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Japan's Fine Ceramics Industry Fulfilling International Obligations

43070100A Tokyo JAPAN 21ST in English Apr 94 p 53

[Article by Jiro Furumoto, chairman, Japan Fine Ceramics Association]

[Text] The consumption of fine ceramics in Japan has grown steadily in the past 10 years, and the market size reached ¥1,200 billion in 1991. However, the Japanese economy entered a phase of general recession in the latter half of 1991 and the ceramics demand in major user industries including electric machinery, electronics and automobiles is stagnating. The production of fine ceramics slowed down and their output in 1992 stayed at nearly the same level as in the previous year.

As is well known, fine ceramics are endowed with several distinguishing features not possessed by conventional materials such as heat and corrosion resistance, heat conductivity and permeability, with the possibility of enhancing these characteristics further. Hence, fine ceramics are ranked as the No. 1 material for the coming generation. Hitherto fine ceramics as a functional material mainly for electromagnetic applications accounted for 65% of production. But the advance into structural materials is regarded as indispensable for fine ceramics to achieve further expansion. The industry should concentrate all efforts for the development of manufacturing and application technologies and quality control in this direction.

Numerous obstacles must be surmounted such as the intrinsic brittleness of fine ceramics, guaranteeing of reliability and improved precision in order to expand their application as structural material. But we expect that the outstanding characteristics of fine ceramics and their small chance of contamination of the environment will contribute to the solution of these problems in view of the growing significance of global environmental problems and energy saving in recent years.

The development of the ceramic gas turbine is energetically promoted in Japan at present. The application of fine ceramics in this turbine opens the way for energy saving through higher entrance temperature and no need for vane cooling. Joint research is conducted by the government, universities and private-sector companies on the high-temperature separation, recovery and re-use of CO_2, which will undoubtedly contribute to the solution of environmental problems.

We regard it as essential to realize and industrialize the applications of fine ceramics as structural material step by step based on these research results.

The research and development of the "High Dimension Structural Control Harmonized Inorganic Material" centering on so-called "synergy ceramics" is to be inaugurated in 1994 as a new state project. This project means one step forward from monolithic sintered materials to ceramic materials of a new type in which the structure in several layers can be controlled from atomic to macro levels. The expertise accumulated over the past 10 years will be mobilized in the new materials, which may mean a breakthrough in the fine ceramics industry.

I think the establishment of infrastructure is essential in any new industry. Since its establishment, the Japan Fine Ceramics Association (JFCA) has been consistently working on the standardization of the fine ceramics industry and has cooperated for the drafting of JIS (Japan Industrial Standards) in 16 items related to testing and evaluation of this material.

In April 1992 Japan proposed to ISO (International Standard Organization) the establishment of a technical committee on fine ceramics, and the proposal was approved in November of the same year, leading to the founding of TC 206 with Japan as executive secretary.

Dr. Takashi Kanno of Japan was appointed international secretary, and Dr. Schneider, NIST, United States, was appointed chairman of the new committee. Japan National Council for International Standardization of Fine Ceramics was founded in July 1993 to fulfill the tasks of Japan as the international secretary country. JFCA is to energetically support international standardization as the central theme of the standardization task performed by the organization hitherto. The International Task Committee and the Domestic Task Committee representing Japan have started activities with the participation of specialists from wide circles. The first general conference of the technical committee is scheduled to take place in Tokyo in the first half of 1994. We are aware of our heavy responsibility to bring success to this conference which will become the place of Japan's first contribution to the development of the fine ceramics industry and new material technology.

In conclusion, I should emphasize that Japan has been endeavoring in the past decade for the development of basic and application technologies of fine ceramics which have attracted worldwide attention as a new material supporting the next century. The economic changes in recent years should not deter our activities for early introduction of standards and compiling of databases in order to lay a firm foundation for the new-born industry. I sincerely wish for understanding and cooperation of all people concerned.

Japan's Fine Ceramics Industry

43070100B Tokyo JAPAN 21ST in English Apr 94 pp 55-66

[Article by Shigeo Tani, director, Fine Ceramics Office, MITI]

[Text]

1. Fine Ceramics Supporting the Vanguard Industries of the 21st Century

1. What are Fine Ceramics?

According to a report compiled in December 1989 by the Fine Ceramics Industry Basic Problems Group (a private

group established by the director of the Consumer Goods Industries Bureau in the Ministry of International Trade and Industry), fine ceramics are defined as follows:

> "Inorganic materials possessing a minute structure due to the combination chiefly of many crystal grains manufactured and processed to meet certain purposes by controlling the minute composition and forms of materials. They possess a controlled chemical composition through the use of refined and coordinated basic materials produced by putting into play specific functions possessed by ceramics."

Whereas ceramics have always been regarded as natural inorganic substances hardened by baking, such as porcelain, glass and cement, fine ceramics are things manufactured so as to bring out specific functions to the maximum through the use of man-made materials such as aluminum, zirconia and silicon nitride. They can possess various specific properties depending on the material, selection of chemical composition, and method and condition of sintering. They include such special characteristics as extreme hardness and abrasion resistance, piezoelectricity, insulation, electric induction, heat resistance, heat conduction, corrosion resistance and high penetration.

The term "fine ceramics" has established itself in Japan, but in Europe and the United States such expressions as "advanced ceramics," "high technology ceramics" and "high performance ceramics" are in use.

2. History of Fine Ceramics Industry

As mentioned above, the use of fine ceramics has widely entered our lives in various forms since they possess outstanding special characteristics not to be found in traditional materials. But their history as materials and as an industry is still short.

Research and development of fine ceramics possessing electric and magnetic properties (sometimes called functional materials) are said to have entered a new phase in about 1930 when their special electromagnetic features became known. Thereafter, the application of such functional ceramics as materials for various types of sensors, spark plugs, condensers and IC packages grew along with the development of electric machinery and information communications industries in the period starting from 1950. They sustained further growth of these industries.

Meanwhile, the development of the fine ceramics industry, which was based on such features as heat resistance and extreme hardness, abrasion and corrosion resistance (we refer to them as structural materials) is believed to have originated during the Cold War period after World War II when the United States felt a sense of crisis with respect to the acquisition of rare metals and developed a new heat resistant material called "cermet."

Research and development of such structural ceramics got under way in the world on a full scale starting in 1972 at the time of the oil crisis when they gave rise to high expectations because of improved thermal efficiency and energy saving effect through heat resistance superior to that of metals. Full-scale development was started on heat and abrasion resistant structural materials beginning with the application to gas turbines and then to automobile parts and bearings.

3. Industry's Present Situation and Outlook

(1) Present Situation

Demand for fine ceramics in Japan has been growing annually. The country boasted a market size of about ¥1.2 trillion in 1991. According to a fine ceramics industry survey conducted by the Japan Fine Ceramics Association (JFCA), the value of production registered an annual growth of 3-10% from 1986 to 1991 centering on electronic parts. But the collapse of the so-called "bubble economy" in Japan in the latter half of 1991 with accompanying plummeting of land and stock prices has ushered in a period of structural adjustment with continuous stagnation of personal consumption and equipment investment. Hence, the production value of fine ceramics in 1992 remained around ¥1,200 billion due to the slowdown of the chief client industries including electric machinery, electronics and automobiles.

A breakdown of the ¥1.2 trillion in sales during 1992 shows that functional ceramics, centered on electromagnetic uses, accounted for approximately 65% of overall sales—an overwhelming percentage compared to other uses.

(2) Future Outlook

According to the abovementioned report of the Fine Ceramics Industry Basic Problems Group issued in December 1989, the scale of Japan's fine ceramics market is projected at around ¥6 trillion in the year 2000, approximately five times the current size. This projection was based on the expectation of rapid development in the utilization and diffusion of machinery and heat-related material parts. It was once regarded as certain that the ratio of structural materials would register a marked growth in the near future. Up until the present moment, however, the commercial application, utilization and diffusion of fine ceramics in the structural materials field have not lived up to expectations. One reason is the sluggish economic situation, which is more prolonged than thought at first. It also indicates that many technological problems remain to be surmounted.

However, efforts will be stepped up in the field of functional materials to achieve a higher level of performance and more sophisticated functions. Further expansion is anticipated due to new uses, but it is believed that the market is already maturing to some extent. As for structural materials, various related problems are awaiting solution. Along with rising interest in global

environmental problems in recent years, expectations are likely to grow with respect to outstanding heat-resistant fine ceramic materials in order to improve heat efficiency and to save energy. We also anticipate greater practical application, utilization and diffusion of structural ceramics. We think that R&D must be promoted to overcome technical problems.

II. Development of the Fine Ceramics Industry

1. Problems Facing the Industry

Fine ceramics possess various outstanding qualities lacking in traditional materials. By virtue of these special features, they will find applications over a broad area covering electronics, aerospace, motor vehicles, energy and medicine. In addition, expectations are mounting for energy saving based on the utilization of the superb qualities of fine ceramics along with the rising concern over global environmental problems in recent years.

Japan's level of fine ceramics-related technology at present is regarded to be at a considerably high level. However, the fine ceramics industry as a new growing materials industry of the 21st century will have to perform various tasks in order to achieve further development. They are briefly enumerated as follows:

1) further promotion of materials research and development;

2) research on materials processes and development, and cost reduction through corporate efforts;

3) establishment and standardization of testing and evaluation methods as infrastructure of R&D, application and diffusion;

4) promotion of international cooperation in the field of R&D and standardization.

Table 1. Production of Fine Ceramic Parts and Materials (Units: ¥ 100 million, %)

	Electromagnetic	Mechanical	Optical	Chemical and medical	Thermal	Others	Total
1983	5,737	390	173	298	266	86)	6,950
	(82.5)	5.6)	(2.5)	(4.3)	(3.9)	(1.2)	(100)
1984	6,187	1,005	151	522	199	6	8,070
	(76.7)	(12.4)	(1.9)	(6.5)	(2.4)	(0.1)	(100)
1985	6,008	1,060	322	595	(580	12	8,577
	(70.0)	(12.4)	(3.8)	(6.9)	6.8)	(0.1)	(100)
1986	6,216	988	578	602	472	23	8,879
	(70.0)	(11.1)	(6.5)	(6.8)	(5.3)	(0.3)	(100)
1987	6,898	1,315	649	619	482	26	9,989
	(69.1)	(13.2)	(6.5)	(6.2)	(4.8)	(0.2)	(100)
1988	7,395	1,650	517	640	562	35	10,799
	(68.5)	(15.3)	(4.8)	(5.9)	(5.2)	(0.3)	(100)
1989	7,473	1,708	613	659	578	45	11,076
	(67.5)	(15.4)	(5.5)	(5.9)	(5.2)	(0.4)	(100)
1990	7,904	1,913	749	809	532	71	11,978
	(66.0)	(17.0)	(7.0)	(7.0)	(4.0)	(1.0)	(100)
1991	8,139	2,071	813	776	536	85	12,4201
	(66.0)	(17.0)	(7.0)	(6.0)	(4.0)	(1.0)	(100)
1992	8,168	2,070	807	827	526	95	12,493
	(65.0)	(17.0)	(6.0)	(7.0)	(4.0)	(1.0)	(100)

Source: JFCA's Industrial Trend Survey

Table 2. Classification of Fine Ceramic Parts and Materials

Classification	Typical products
Electric	Semiconductors, IC parts (IC packages, substrates, thermistors, varistors, etc.), magnetic materials (ferrite cores, ferrite magnets, etc.), other products (piezoelectric elements, condensers, spark plugs, HF insulators, etc.)
Mechanical	Tools, ultra-hard materials (cutting tools, grinding materials, WC dies, etc.), compound materials (cermet, carbon fiber, etc.), abrasion resistant materials (mechanical seals, liners, etc.), other products (gauges, etc.)
Optical	Optical fiber, light emitting and phosphorescent materials, masks, etc.
Chemical and medical	Oxygen sensors, catalysts, catalyst carrier for automobiles, other catalyst carriers, artificial teeth, bones and joints
Thermal	High-temperature abrasion resistant materials for automobiles, high-temperature corrosion resistant materials (for thermal treatment equipment of semiconductors, carbon rods, crucibles, etc.), other products (heat generating materials, heat resistant materials, heat resistant fiber, etc.)
Others	Nuclear power materials, products for living and culture

2. Promotion of Research and Development

In order to meet the abovementioned expectations placed on fine ceramics, especially as structural materials, we must overcome their brittleness regarded as the main problem of ceramic materials. Research should be directed at achieving higher functions such as heat and corrosion resistance under exacting conditions of high temperature to open up new application fields.

Fine ceramics R&D in Japan are being vigorously carried out by private enterprises, universities, national research institutes and laboratories throughout the country. They cover both the development of new materials and that of application technology.

Major research and development activities being undertaken as national projects are cited below:

(1) Materials Development

- Fine Ceramics

The materials development project was undertaken from FY1982 to FY1992. The purpose of the project was to perfect basic technologies related to fine ceramics including the attainment of performance and reliability needed in structural materials and the development of the technical design system necessary for overcoming the brittleness of ceramics as industrial materials so as to draw out the desirable qualities of fine ceramics as very promising vanguard materials with outstanding temperature characteristics.

For this purpose, a series of technology developments covering materials synthesis, forming and sintering, as well as processing and bonding were carried out. R&D was undertaken by mutually and organically linking the technologies of designing and evaluation.

The research period was divided into three phases under this project. Phase I (FY1981-83) was devoted to monolithic materials which were test-shaped into simple forms; Phase II (FY1984-87) was devoted to the development of materials and manufacturing processes which satisfied target performance with the use of simply shaped models; and Phase III (FY1988-90) was devoted to the achievement of a new target performance using models of complicated form similar to actual components, including high toughness materials and those applying surface reinforcement technology. During the Final Phase (FY1991-92), all research results were verified on the basis of an evaluation test of integrated model parts applied to a coal gasification ceramic turbine.

- High-Order Structurally Controlled Fusion-Based Inorganic Materials (Synergy Ceramics)

Following the fine ceramics project mentioned above, the research on advanced technology was inaugurated in FY1993 in preparation for the full-scale project planned in FY1994.

The research will be mainly directed at creating new materials by simultaneously controlling the various strata of structures extending from the atomic and molecular levels of inorganic bulk materials to the macro level. It will also seek to clarify technological needs and confirm the possibility of creating new inorganic materials which combine various dynamic, electric and chemical functions.

(2) Development of Utilization Technology

- Ceramic Turbine

The gas turbine, a type of prime mover, features an excellent adaptability to various types of fuels. It also features lightness, small size and low pollution. But the thermal efficiency of a traditional small-size metal turbine is not higher than 35%. A higher degree of thermal efficiency and energy saving is regarded as possible by using ceramics as heat-resistant components where a high temperature (1,350°C) is achieved at the turbine entrance and the vane cooling can be dispensed with.

However, design materials pre-supposing metals are not applicable to fine ceramics as brittle materials. Further advancement, including non-destructive testing methods, is also needed in order to guarantee reliable performance.

In view of the significance of ceramic gas turbines in the energy policy and the need for establishing advanced technology of ceramic parts, the state is promoting the development of co-generation ceramic gas turbines of 300 kW class in a nine-year plan that started in FY1988.

Table 3. Fine Ceramics Related Organizations

1. Japan Fine Ceramics Association	
Established:	November 15, 1986
Address:	3-24-10 Nishi-Shinbashi, Minato-ku, Tokyo Tel. 03-3437-3781
Chairman:	Jiro Furumoto (Chairman, Asahi Glass Co.)
Executive Director:	Minoru Uki
Membership:	188
Principal members:	Asahi Glass, Ishikawajima-Harima, Kyocera, Kurosaki Ceramics, Kobe Steel, Shinagawa Refractories, Showa Denko, Nippon Steel Corp., Sumitomo Chemical, Sumitomo Electric, Denki Kagaku Kogyo, Toshiba, Toyota Motor, Nissan Motor, Nippon Sheet Glass, NGK Insulators, NEC, NGK Spark Plug, Hitachi, Matsushita Electric Industries, Mitsubishi Heavy Industry, Mitsubishi Material, Murata Manufacturing
Business line:	Business related to fine ceramics: 1. Collection and furnishing of information 2 Survey and research on production, distribution, trade and standardization 3 Holding of classes, lecture meetings and seminars
2. Japan Fine Ceramics Center	
Established:	May 7, 1985
Address:	2-4-1 Rokuno, Atsuta-ku, Nagoya Tel. 052-871-3500
Chairman:	Takeshi Hijikata (Counselor, Sumitomo Chemical)
Managing Director:	Masaaki Ohashi (President, Aichi Seiko)
Executive Director:	Hiroshi Okada
Business line:	1. Testing, inspection, verification and evaluation of fine ceramics 2. Examination and inspection 3. Technical guidance and counseling, collection and furnishing of technical data 4. Training of talented persons, international exchange, etc.
3. Japan Far Infrared Rays Association	
Established:	June 1, 1992
Address:	3-20-5 Toranomon, Minato-ku, Tokyo Tel. 03-3438-4108
Chairman:	Toshihito Kohara (President, NGK Insulators)
Executive Director:	Masatoshi Shioda
Membership:	135
Principal members:	Asahi Glass, Osaka Gas, Kuraray, Showa Denko, Nippon Steel, Sumitomo Metal, Denki Kapku Kogyo, Tokyo Gas, Toshiba, Toyota Motor, Nishikawa Sangyo, Nippon Sheet Glass, NGK Insulators, Nippon Light Metal, Japan Vilene, Matsushita Electric Industries, Renown
Business line:	1. Research and survey of far infrared ray related products and technology 2. Collection and furnishing of information 3. Dissemination and enlightenment
4. New Diamond Forum	
Established:	July 26, 1985
Address:	3-24-10 Nishi-Shinbashi, Minato-ku, Tokyo Tel. 03-3437-3989
Chairman:	Osamu Saeki (Counselor, Kobe Steel)
Membership:	About 180 (including private members)
Principal members:	Asahi Diamond, Idemitsu Material, Osaka Diamond, Ogura Jewel Industry, Onoda Cement, Canon, Kyocera, Kobe Steel, Showa Denko, Nippon Steel, Sumitomo Electric, Debias Japan, Tokyo Gas, Toshiba Tungalloy, Tomei Diamond Industries, Toyoda Machine, Nihon Shinku, NEC, Fujitsu Laboratories, Matsushita Electric Industries, Mitsubishi Material

Table 3. Fine Ceramics Related Organizations (Continued)

Business line:	1. Survey and research of new diamond 2. Collection and furnishing of information 3. Holding of lecture meetings and symposiums 4. International exchange and cooperation
5. Japan National Council for International Standardization of Fine Ceramics	
Established:	July 21, 1993
Address:	3-24-10 Nishi-Shinbashi, Minato-ku, Tokyo Tel. 03-3437-3988
Chairman:	Toshihito Kohara (president, NGK Insulators)
Secretary TC206:	Takashi Kanno (Research Center, Asahi Glass)
Membership:	40
Principal members:	Asahi Glass, Ishikawajima-Harima, Kyocera, Nippon Steel, Sumitomo Chemical, Sumitomo Electric, Chubu Electric Power, Denki Kagaku Kogyo, Toshiba, Toyota Motor, NGK Insulators, Hitachi, Mitsubishi Material, Japan Ceramics Association, JFCA, JFCC
Business line:	Following tasks as secretary country of ISO/TC206 1. Support of tasks by the secretary of TC206 2. Dispatching of Japanese representatives to ISO/TC206-related international conferences 3. Study and making of draft plan for committee standards 4. Domestic diffusion of ISO standards Other tasks needed for smooth introduction of international standards of fine ceramics

• Technology for High-Temperature Separation and Recovery of CO_2

Recently the need for reducing the CO_2 emission is keenly felt to prevent global warming. The project, covering a period of 10 years from FY1992, is aimed at developing a system for separating high-temperature $CO_2$2 of over 300°C from the waste gas discharged from large sources such as plants for the re-use of recovered $CO_2$2. The heart of this system is the ceramic separating diaphragm.

3. Promotion of Standardization

(1) Establishment of JIS (Japanese Industrial Standards)

The delay in the standardization of testing and evaluation methods for fine ceramics compared with other materials is hampering the exchange of mutual data, comparison of performance and evaluation. This, reportedly, is one of the factors preventing the promotion of R&D, utilization and diffusion.

The proposal of the special committee on standardization of materials, the Agency of Industrial Science and Technology, listed 219 items related to fine ceramics as needing standardization.

With respect to testing and evaluation methods, 16 JIS standards have been established so far mainly on the initiative of JFCA. Efforts will be made hereafter to vitalize the Japan Fine Ceramics Center (JFCC) which is responsible for testing and evaluation of these materials. In cooperation with JFCA, it will be necessary to establish testing and evaluation methods indispensable for the expanded use of fine ceramics and to seek further promotion of standardization. In addition, materials development and that of testing and evaluation methods should be carried out simultaneously in the R&D project and the research results should be applied to the efficient introduction of standards.

(2) ISO's Approach to International Standardization

Standardization traditionally took the form of rules being established generally after the technology had taken root. But in the field of advanced technology of structural fine ceramics, the standardization of testing and evaluation, commonly accepted by engineers (we call it "Early Stage Standardization"), is being sought while projecting the direction in which technology is likely to proceed, because of the prolonged period of research and development.

The efforts for ceramics standardization were hitherto undertaken separately in various parts of the world as in JIS of Japan, ASTM (C-28 Committee) of the United States and CEN (C-184) of Europe. In addition, international activities in VAMAS and IEA are carried out as pre-standardization research. International standardization as such is not being implemented.

Opportunities for international exchange with respect to fine ceramics, such as international joint research and trade transactions, are destined to increase. The majority of people concerned with fine ceramics in Japan have traditionally voiced the opinion that the standardization of testing and evaluation methods as the common language of engineers should be carried out at an early date at ISO (the International Organization for Standardization) as the common forum with the cooperation of

researchers in all countries and also that Japan should play a more positive role in ISO/TC for international standardization.

For this reason, Japan submitted to ISO in April 1992 a proposal for the establishment of a new TC for fine ceramics and for nominating the Japanese representative as executive secretary. The proposal was referred to an international vote and the establishment of ISO/TC206 was formally approved in December of the same year. Dr. Takashi Kanno was appointed executive secretary of the new TC, while Dr. Schneider of NIST in the United States became chairman. The Japan National Council for International Standardization of Fine Ceramics was newly founded in July 1993 in order to support Dr. Kanno's duties as the secretary of TC206 and to prepare the domestic environment for fulfilling Japan's responsibility as the caretaking country.

As of January 1994, P-members or active members of ISO/TC206 are eight countries: the United States, the Republic of Korea, Indonesia, Malaysia, Jamaica, Australia, Russia and Japan.

The First General Convention of TC206 is to take place in Tokyo in late May of this year. We ardently hope that ISO/TC206 will serve as the forum where the activities for international standardization of fine ceramics will be energized under the close cooperation and liaison among the United States, countries of Asia and Oceania and CEN participating countries of Europe.

4. New Utilization Area for Fine Ceramics

There has been mounting interest in new utilization areas for fine ceramics such as new diamonds (artificial diamonds) and far infrared ray ceramics. The following policy is going to be implemented in order to cultivate fine ceramics as a new industry hereafter.

(1) Policy on the Far Infrared Ray Industry

Far infrared rays as electromagnetic waves corresponding to heat rays are known to be effective in heating and drying, and have long been industrially applied for painting automobile bodies, etc. Because of the outstanding radiation characteristics of far infrared rays, fine ceramics are expected to be applied to new products using such rays and find new markets. In recent years, fine ceramics have been applied to the so-called "non-heating sector" with the emergence of diverse new products.

However, some products, especially those used chiefly in normal temperature range, do not necessarily possess any clear scientific basis to guarantee results. We recommend, therefore, research and study to grasp the actual situation of the far infrared ray related industries, measurement methods of radiation and the evaluation of radiation effect. Against this background, the Japan Far Infrared Ray Association (JIRA) was founded in June 1992 to perform various tasks such as the survey of far infrared ray related industries, research on technical problems of far infrared rays, drafting of voluntary guidelines for the protection of consumers and the establishment of measurement and evaluation methods.

(2) Policy on the New Diamond Industry

New diamond is the artificial diamond made through ultra-high pressure sintering or chemical process (including gas phase synthesis).

Diamond is crystallized carbon formed under ultra-high temperature and pressure. It may be called an "ultra-hard ceramic," the hardest material on the earth. Besides hardness, diamond possesses high thermal conductivity, low thermal expansion and excellent optical and electronic properties.

Artificial diamond has found applications mainly as cemented carbide tools (tools for cutting and grinding) at present. The development of new application fields is awaited by utilizing the abovementioned outstanding characteristics. Survey and research are being conducted on the manufacturing and application technology of artificial diamond which will form a new industry in the future.

Crystal Growth Experiments on Compound Semiconductor on the Earth in Preparation for SFU Mission

43070090A Tokyo IHI ENGINEERING REVIEW in English Apr 94 pp 45-49

[Article by Katsumi Takahashi, doctor of engineering, manager, Satoshi Adachi, doctor of engineering, Yuji Ikegami, manager, and Hiromi Yamaguchi, all of the Exploratory Technology Department-1, Research Institute; Jun-ichi Ochiai, doctor of engineering, manager, Space Experiment System Development Department; and Hiroshi Sakai, manager, Institute for Unmanned Space Experiment Free Flyer]

[Text]

1. Introduction

A satellite called SFU[1,2] will be launched in February 1995 jointly by the Ministry of International Trade and Industry (MITI), the Ministry of Education, Culture and Science, and the Science and Technology Agency using the H-II rocket presently being developed. Two organizations related to MITI, New Energy and Industrial Technology Development Organization (NEDO) and Institute for Unmanned Space Experiment Free Flyer (USEF) are coordinating the experiments on compound semiconductors in space. Seven companies are preparing these space experiments, which include eight subjects (Table 1). We will conduct two of these subjects.[3,4]

Table 1. Subjects of Space Experiments by Using SFU

Subject No.	Semiconductors	Crystal growth technique	Furnaces
1*	GaAs Bridgeman method	Gradient heating furnace	
2	CdTe	Bridgeman method	Isothermal furnace
3	CdS	Vapor phase epitaxy	Gradient heating furnace
4	AlGaAs	Liquid phase epitaxy	Isothermal furnace
5	InP	Liquid phase epitaxy	Gradient heating furnace
6	InGaP	Vapor phase epitaxy	Gradient heating furnace
7*	InP	Traveling heater method	Mirror heating furnace
8	InGaAs	Traveling heater method	Mirror heating furnace

(Note) *: Represents that the principal investigator is in IHI

Our Research Institute has led from the proposal of the subjects (1987) to the planning and execution of the experiments. The semiconductors subjected to the space experiments are gallium arsenide (GaAs) and indium phosphide (InP) (Table 1). The Bridgeman method, one of melt-growth methods, and the traveling heater method (THM), one of solution-growth methods, are used for the growth of GaAs and InP crystals, respectively. The main object of the GaAs crystal growth experiment is to obtain crystals containing a uniform concentration of impurities by growing the crystals under conditions dominated by the diffusion process.[3] Meanwhile, the main object of the InP crystal growth experiment is to investigate the effect of convection produced in the solution on crystal quality.[4]

To achieve these objects, experiments on the earth have been carried out on the establishment of experimental conditions and the evaluation of crystal quality. The furnaces used in the experiments on the earth are electric furnaces owned by IHI (hereafter referred to as "IHI furnaces") and electric furnaces owned by USEF for experiments on the earth of the same types as those loaded on the SFU (hereafter called the "ground furnaces"). The IHI furnaces have been used primarily for the examination of growth conditions for space experiments and the confirmation of safety. The ground furnaces have been used to adjust experimental parameters so as not to exceed furnace limitations. The ground furnaces will be used to grow 1g-reference crystals for comparison with the crystals grown in space.

In this paper, the results of the crystal growth experiments on the earth and the evaluation of the quality of the crystals obtained in these experiments are described.

2. Experimental Setup

2.1 Gallium arsenide

Crystals of gallium arsenide (GaAs) are grown by the Bridgeman method. This method is one of melt-growth techniques in which the position of the melting point is kept away from the seed to freeze the melt unidirectionally from the seed side. For such a growth method, an electric furnace called a complex heating furnace or a gradient heating furnace (GHF) is suitable. In the present experiments, both the IHI furnace and the ground furnace are GHFS. A ground furnace with performance equivalent to that loaded on the SFU[2] is schematically shown in Figure 1. The ground furnace consists of a heating and a holding furnace, between which is installed a heat pipe to produce a steep temperature gradient.

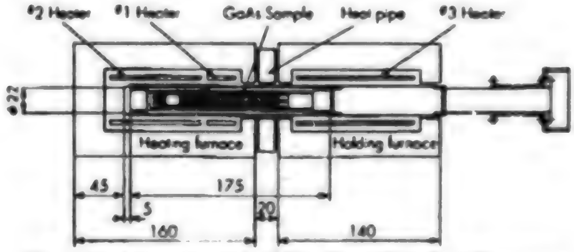

Figure 1. Arrangement of Gradient Heating Furnace (Unit: mm)

A tantalum cartridge containing the sample for growth is inserted into the ground furnace. The outer diameter of the cartridge is 25 mm, and its surface is coated with alumina to improve emissibility. Figure 1 shows the configuration when the tantalum cartridge has been inserted to the base point of the furnace.

The maximum size of the ampule to be contained in the tantalum cartridge is 23.6 mm in diameter and 220 mm in length. The arrangement of the ampule for GaAs melt-growth in space is shown Figure 2. The ampule has a three-layer structure.[3] The innermost layer is a crucible made of boron nitride to hold molten GaAs. The middle one is a hermetically sealed case made of quartz to hold the crucible in a vacuum. The outermost layer is a cover made of graphite to protect the hermetically sealed case from expansion and deformation. In addition, cushion members are arranged as required to absorb stress produced by the difference in thermal expansion coefficients during cooling.

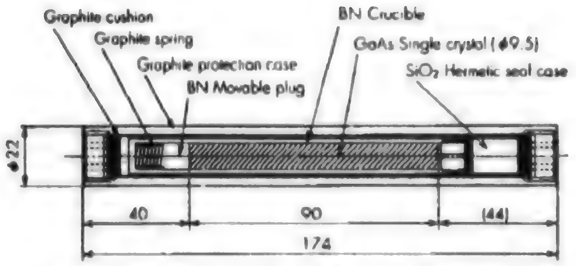

Figure 2. Arrangement of Ampule for GaAs Melt-Growth in Space (Unit: mm)

The volume of compound semiconductors with a zinc blend structure, such as GaAs and InP, decreases by about 10% when they melt. To absorb this decrease in volume and to keep molten GaAs always in contact with the wall of the crucible, graphite springs are arranged in the crucible.

2.2 Indium phosphide

Indium phosphide (InP) crystals are grown by THM. THM is one of the techniques in which the solvent zone held between the seed and the feed polycrystalline is locally heated, and the solvent zone is moved towards the feed side by moving the furnace or the ampule to grow single crystal on the seed. An electric furnace which enables local heating, such as a mirror heating furnace (MHF), is suitable for this method. In the present experiments, the IHI furnace and the ground furnace are MHFS. The construction of a ground furnace with performance equivalent to that of the MHF loaded on SFU is shown in Figure 3.[2] An MHF is an electric furnace to heat the sample by focusing infrared rays on the sample using a mono-ellipsoidal mirror. A halogen lamp is placed on one focal point of the MHF as the infrared source, and an ampule of a maximum of 30 mm in diameter and 120 mm in length can be placed on the other focal point.

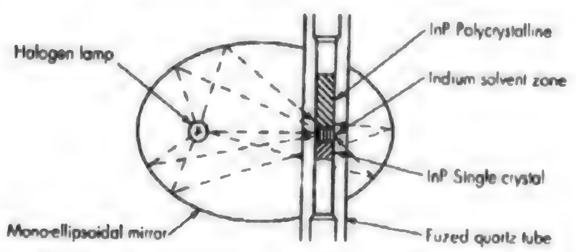

Figure 3. Construction of Mirror Heating Furnace

The structure of the ampule for InP solution-growth is shown in Figure 4. The ampule consists of a hermetically sealed section, a cushion, a feed polycrystalline, a solvent zone, a graphite rod, a cushion, and a hermetically sealed section, arranged along the direction of sample movement. The material of the solvent zone is indium (In). In solution growth, the temperature of the feed-solvent interface must be higher than that of the seed-solvent interface. Their temperature difference becomes the driving force to dissolve the feed into the solvent zone and to deposit InP on the seed. The temperature gradient at the seed-solvent interface determines the length and quality of the single grown crystal. In this ampule, the temperature gradient in the seed-solvent interface is controlled by placing the graphite rod adjacent to the seed crystal.[5]

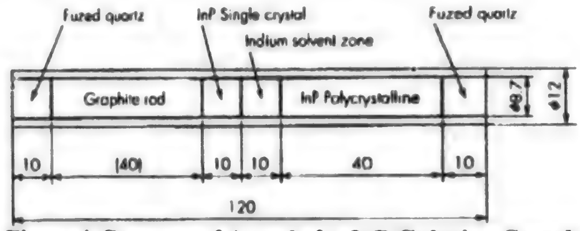

Figure 4. Structure of Ampule for InP Solution-Growth in Space

To absorb stress produced by the thermal expansion of graphite and InP, cushion members are provided. Unlike InP, In increases in volume on melting compared with the solid. Therefore, the seed crystal is fitted in the quartz tube with high accuracy so that molten In does not flow around the side of the seed crystal.

3. Experimental Results and Discussion

3.1 Gallium arsenide

Gallium arsenide generates an arsenide (As) saturated vapor pressure of about 1 atm upon melting. Since As and its compounds are toxic, leakage of As vapor is not allowed. Therefore, GaAs crystal growth experiments were carried out using the IHI furnace to confirm the safety of the ampule. Figure 5 shows the ampule after the growth experiment of GaAs. The graphite protection case is shown in the upper portion, and the quartz hermetic seal case in the lower portion. A crucible made of boron nitride is contained in the hermetic seal case. From Figure 5, it is observed that the surface of the hermetic seal case has lost some transparency due to the texture of the carbon cloth, but that none of the parts constituting the ampule, the protection case, hermetic seal case and crucible, has been broken.

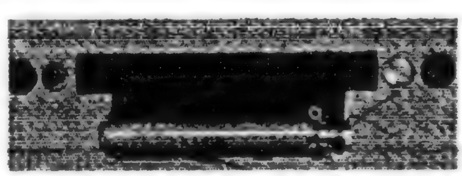

Figure 5. Ampule After Growth Experiment of GaAs

After confirming safety by using the IHI furnace, crystal growth experiments were carried out by using ampules of the same structure in the ground furnace. The final

object of the experiments was to obtain 1g-reference crystals for comparison by operating the furnace under the same conditions as in space experiments, except for the condition of gravity. The experimental sequence is shown in Figure 6.

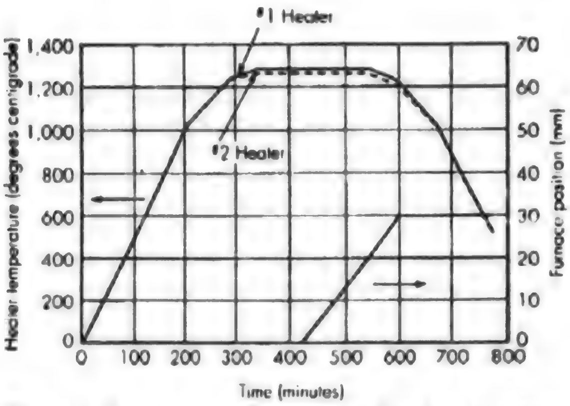

Figure 6. Experimental Sequence of Gradient Heating Furnace

Figure 7 shows the GaAs sample after the growth experiment. The growth plane is the [III] B plane. In Figure 7, the part on the left-hand side with metallic gloss is the seed crystal, and the part on the right-hand side with less gloss is the grown crystal. The interface between them is the initial solid-liquid interface. After this crystal is cut along the [110] plane in the growth direction, the position and the shape of the initial solid-liquid interface is measured by etching after chemical polishing. The used etchant is the AB etchant, of which the solutes are chromium oxide and silver nitrate, and the solvents are hydrogen fluoride and water.

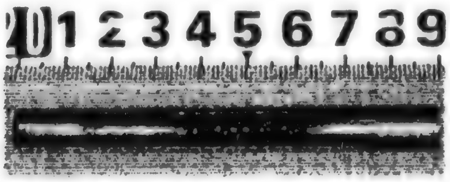

Figure 7. GaAs Sample After Growth Experiment Using Gradient Heating Furnace

Figure 8 shows a micrograph of the longitudinal section of etched GaAs. In this micrograph, the curve on the right-hand side is the initial solid-liquid interface. Crystal growth started leftward from this interface. Since the initial interface is convex toward the seed side, it is expected to solidify from the wall of the crucible during crystal growth. This agrees very well with the direction of the growth of grain boundaries. In the future, the materials and dimensions of the ampule should be improved so that the initial interface is convex toward the melt side. It is found from the micrograph, however, that even when the shape of the initial interface is convex toward the seed side, a single crystal of a minimum length of about 2 mm and a maximum length of about 9 mm has been obtained. These lengths are 16% and 60% of the crystal growth, respectively.

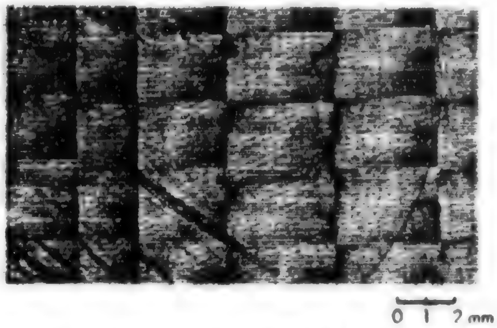

Figure 8. Longitudinal Section of Etched GaAs

The distribution of dopant concentration of this sample was measured by its infrared transmission image, one method for the optical analysis of crystal characteristics. The result is shown in Figure 9. The bright arciform boundary is the initial interface. In this measurement, transmitted light intensity increased as the dopant concentration decreased. From Figure 9, therefore, dopant concentration should monotonously increase with the growth of the crystal. This result agrees with the monotonous increase in dopant concentration in crystal growth on the earth, which is dominated by thermal convection.

The Hall effect is measured as one way to evaluate electrical properties. The dependence of hole mobility on the growth direction is shown in Figure 10. Thin solid lines represent hole mobility, and thick solid lines represent etch-pit density, which is related to defect density. From Figure 10, it is found that in the initial stage of crystal growth, the hole mobility is equivalent to that of the seed. It is also found that with the progress of growth, the hole mobility decreased as the etch-pit density increased.

Figure 9. Infrared Transmission Image of Longitudinal Section of Grown GaAs

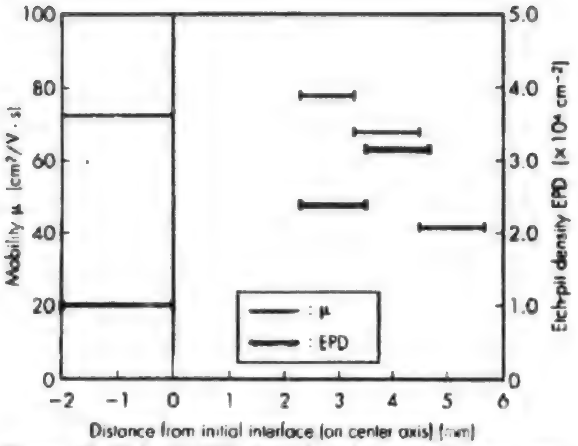

Figure 10. Hole Mobility Obtained by Hall Measurements

3.2 Indium phosphide

Figure 11 shows one of the ampules used in the present experiments. The ampules for space experiments have virtually the same configuration. The part with metallic gloss is the In solvent zone, where infrared rays from the mirror heating furnace are condensed. The growth plane is the [111] B plane. Heating was carried out in the range of the maximum solvent-zone temperature 880°C to 1,000°C. The moving speed of the furnace was 0.05 to 0.2 mm/h. Because of the single-mirror heating furnace, the ampule was rotated at 5 rpm to improve the temperature distribution in the interface in the azimuthal direction.


Figure 11. Picture of InP Ampule for Space Experiments

Figure 12 shows the temperature dependence of InP crystal growth length on the maximum temperature. In Figure 12, open circles (o) represent experimentally obtained data. It is found that as the maximum temperature decreases from 1,000°C to 900°C, the growth length of the single crystal increased up to about 2 mm. The obtained length is considerably long although the present growth technique is one of liquid phase epitaxial growth. The optimum temperature should be between 900°C and 880°C. The solid line in Figure 12 represents the possibility of constitutional supercooling (C/C_{sat}) estimated from the results of numerical calculation of the flow in the solvent zone under the IG condition, the distribution of P concentrations, and temperature distribution.[4] Constitutional supercooling is an index of polycrystallization, and single crystals are obtained more easily as its value decreases. When the temperature falls to 900°C, the index value decreases and becomes virtually constant below 900°C. This agrees well with the results of the experiments. In the space experiments, the investigation of constitutional supercooling should be worthwhile from the standpoint of comparison between Ig and Og crystals.

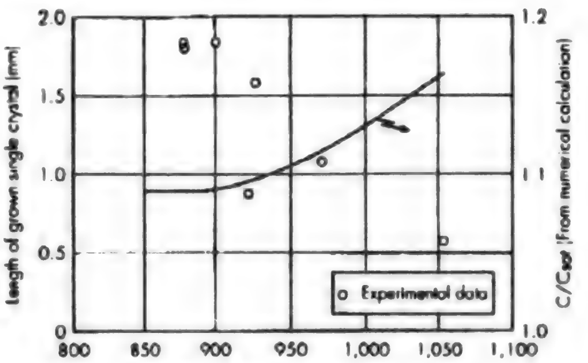

Figure 12. Temperature Dependence of InP Crystal Growth Length and Constitutional Supercooling in In Solvent

The temperature dependence of etch-pit density (EPD), which is related to crystal quality, is shown in Figure 13. It is found that as the maximum temperature falls, the EPD value becomes smaller and the crystal quality improves. The effect of reducing the defects is found to be larger with Zn dopant.

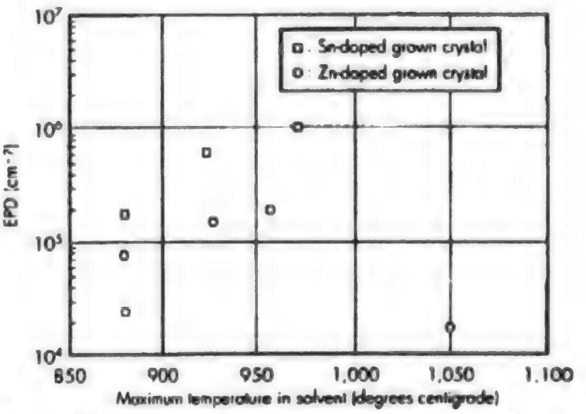

Figure 13. Temperature Dependence of Etch-Pit Density on InP Crystal

Figure 14 shows a micrograph of the grown InP crystal cut along the [211] plane in the growth direction, and etched by the AB etchant. Rugged streaks observed in the

grown part, called striations, provide information on flow. It is expected that there is more of a tendency for striations to be produced on the earth than there is in space.

Figure 14. Picture of [211] Plane of InP Crystal

Photo-luminescence intensity is measured as one method for the optical analysis of crystal quality. The results of mapping of the full width half maximum at the wavelength with peak spectrum on the [111] plane is shown in Figure 15. From Figure 15, it is observed that the yellow region [the lighter shaded portion] at the center has high Zn dopant concentration, while the blue region [the darker shaded region] on the periphery has low dopant concentration. The shape of the interface should be convex.

Figure 15. Distribution of Photo-Luminescence Strength [111] Plane of InP Growth Crystal

The etch-pits of InP include D-pits related to dislocation and S-pits which have been considered to be related to impurity concentration.[6] Figure 16 shows the relationship between photo-luminescence intensity and S-pit density in an InP crystal. It is seen that the S-pit density increases with photo-luminescence intensity, that is, with impurity concentration. In the present experiments, it is confirmed that S pits are derived from impurities.

4.Conclusion

4.1 Gallium arsenide

Safety was assured by using ampules of a three-layer structure. Crystals are grown by using these ampules in

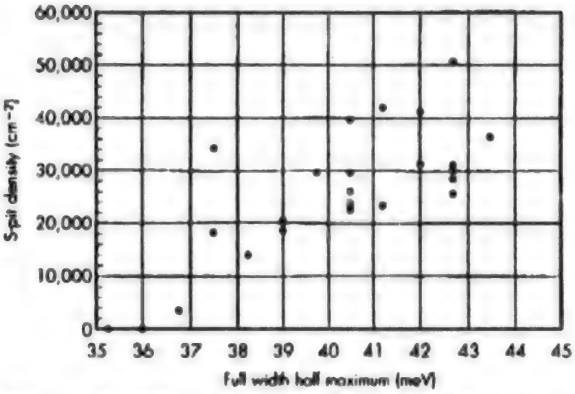

Figure 16. Relationship Between Photo-Luminescence Strength and S-Pit Density in InP Growth Crystal

the ground furnace, and cut in the growth direction for crystallographical evaluation. The results showed that although the shape of the initial solid-liquid interface was convex toward the seed crystal side, 16% and 60% of the length of grown crystal was composed of a single crystal in the shortest and the longest parts, respectively.

Infrared transmission images were first taken in order to diagnose the characteristics of crystal quality, and the distribution of dopant concentration was obtained. The results showed that dopant concentration increases monotonously as the crystal grows. This suggests that crystal growth occurred under the conditions that the thermal convection was dominated. The Hall effect of single crystals was then measured. It was found that hole mobility was nearly equal to that of the seed in the initial stage of growth, but then decreased with increasing etch-pit density.

4.2 Indium phosphide

The optimum conditions for the crystal growth of InP by THM were clarified. Single crystals about 2 mm long were obtained at a maximum temperature between 880°C and 900°C. The main reason for polycrystallization should be constitutional supercooling, and the index obtained by numerical calculation agreed well with the results of the experiment. It was also found that the lower the maximum temperature, the lower the EPD value and the better the crystal quality. By etching the [211] plane, striations indicating the effect of thermal convection proper to lg were observed. It is expected that comparison of the appearance of striations on the earth and those in space will reveal differences in fluid behavior.

Photo-luminescence was measured to evaluate crystal properties, and dopant distribution on the [111] plane was confirmed. It was also confirmed from photo-luminescence measurement that S-pits, which had been expected to be caused by impurities, are indeed related to impurity concentration.

Acknowledgment

The present study is being performed under the commission of the New Energy and Industrial Technology Development Organization (NEDO).

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Proceedings of the International Workshop on Integrated Inorganic Materials

Role of 'Synergy' in Design of Ceramic Microstructures

43070089A Tokyo KOJI KOZO SEIGYO YUGO MUKI ZAIRYO in English 22 Mar 94 p 1

[Proceedings and abstracts of the International Workshop on Integrated Inorganic Materials held 22 Mar 94 in Nagoya, Japan, sponsored by New Energy and Industrial Technology Development Organization (NEDO) and Japan Fine Ceramics Association (JFCA); Article by Richard J. Brook, Department of Materials, University of Oxford]

[Text] Many of the important industrial objectives of the next decade such as increased efficiency in energy generation, storage and utilization or increased environmental compatibility in transport systems depend upon the successful development of ceramic components. Functionally active materials such as solid electrolytes in fuel cells and batteries or inert structural materials such as components in turbines or engines must all be mechanically reliable and must be suitable for fabrication at competitive cost. The development of reliable, cost-effective ceramics is, therefore, a major requirement for progress in industrial technology.

One solution of this requirement is to develop ceramics which exploit "synergy." This word has as its original meaning the positive interaction between two or more separate structures or ideas in such a way that the result brings benefits greater than can be obtained by the separate parts alone.

In the case of ceramics, an example of the "structural" meaning of "synergy" is a material which can compensate for errors in its manufacture (flaw) or in its application (damage) by using combinations of microstructural configurations to respond to imposed loads so that immediate mechanical failure is avoided; processing methods must be developed which are therefore capable of providing the required structures and which at the same time give full attention to opportunities for process cost minimization.

An example of the "ideas" meaning of synergy is the mutual interaction which now exists between the simulation or modelling of the behavior of a material and the exact observation of the behavior by experiment. This synergy is now extremely promising and the exploitation of "totally designed microstructures" offers one of the best opportunities for the profitable development of advanced ceramics.

An important goal is now to develop a strategy for future work. In this connection, the Japanese proposal for international collaboration in high risk research themes and for the identification of clear normative targets (comprehensive microstructure design; synergy ceramics) are stimulating contributions to the mastery of ceramics as an achievement that will bring benefits worldwide.

Development of 'Synergy Ceramics' With Integrated Structure and Function

43070089B Tokyo KOJI KOZO SEIGYO YUGO MUKI ZAIRYO in English 22 Mar 94 pp 3-5]

[Article by Masahiko Shimada]

[Text] Advanced ceramics have unique properties which make them candidate materials for a diverse set of applications ranging from heat engines (high-temperature structural ceramics) to electric power transmission (new superconducting ceramics with high transition temperatures). Their unique properties are a consequence of not only their chemistry, bonding and crystal structure, but also of the microstructures developed during processing. It is useful to consider the microstructure of advanced ceramics at four levels of structural scale: the atomic scale, the manometer scale, the micron scale, and finally the macro scale.

Al the atomic scale, efforts devoted to the synthesis of new ceramic materials, the formation of solid solution systems, chemical modification by ion implantation, and other similar efforts show that by controlling the atomic scale microstructure, property modification and improvement can be achieved. As a result, it is expected that by controlling the atomic scale microstructure, new and improved physical and chemical characteristics manifested by excellent electrical, magnetic, optical, and mechanical properties can be developed in advanced ceramics.

Microstructure at the nanometer scale is developed during the formation of composites produced by mixing nanoscale particles, and in composites that include intragranular and intergranular dispersions of nanosize grains. By dispersing different types of nanosize grains within a matrix in a controlled fashion, it is expected that composites exhibiting high fracture strength, high fracture toughness, and high-temperature creep resistance will be developed.

At the micron scale, the key microstructural elements will include dispersions of grains (possibly including nonequiaxed grains), fibers, and whiskers within the materials. Properly designing microstructures at this level is expected to improve the mechanical properties of many advanced ceramics.

Finally, the macroscale microstructure will involve the integration of atomic, nano, and micron-scale microstructures, as well as the assembly of smaller components of similar or dissimilar chemistry and microstructure into larger multi-component multi-material assemblies.

Representative processing methods for four levels of structure scale are listed in Table 1.

Table 1. Methods for Each Scale Structure Control

Atomic-molecular-scale	Nano-scale	Micro-scale	Macro-scale	
Methods	Solid solution	Particle dispersion	Particle dispersion	Fiber reinforcement
	Superlattice	Precipitation, phase separation	Whisker reinforcement	Compositional gradient
	Amorphous	Sol-gel	Grain growth	Lamination
	Ion implantation	Vapor phase synthesis	Liquid phase sintering	Plasma coating
			Coating	

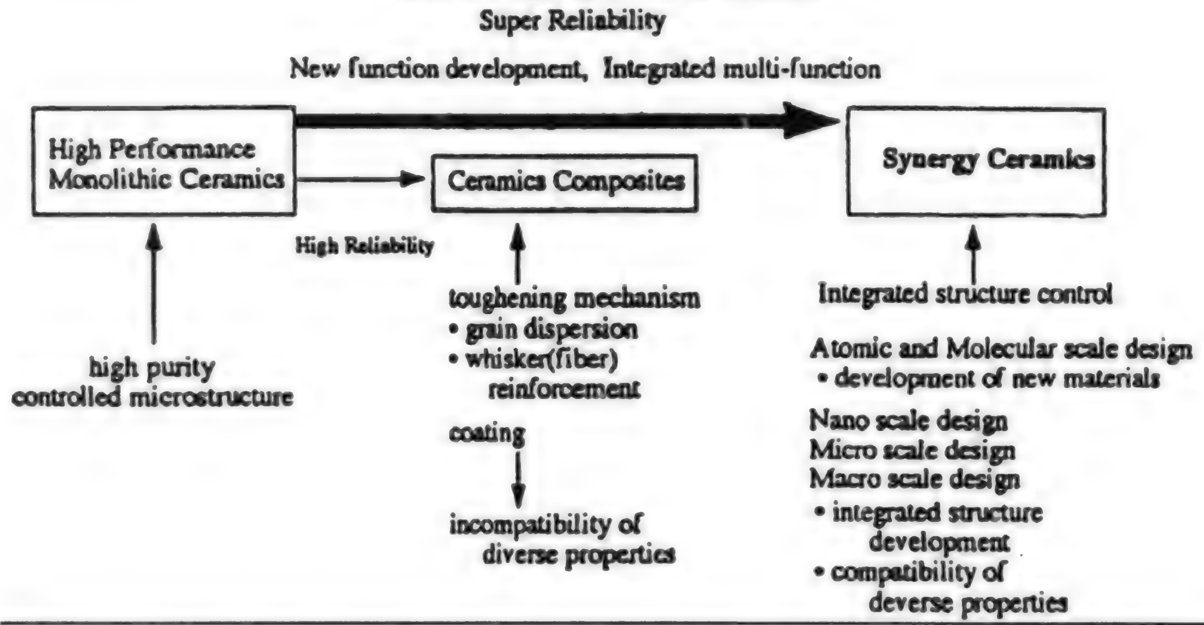
At the present time, more widespread utilization of ceramics is inhibited by property variability. It is widely recognized that this variability stems from inadvertently introduced flaws and structural inhomogeneities that are developed during the processing, and degrade the strength of fired structural ceramics. Thus, the development of ceramics with improved and more tightly bounded properties for structural (and other) applications hinges on improved processing, increased control over the microstructure introduced during the processing, improved understanding of microstructural evolution and interface properties, and improved methods of integrating and combining such improved ceramics in larger multi-material structures.

In the presence of serious global environmental problems, it has become imperative to make a fast transition from the current technologies into the technologies which save energy and resource and contribute to the reduction of environmental pollution. These new technologies require for the development of high performance and super reliability materials having better properties with a longer life under more severe operating conditions. Ceramics seem to be promising materials to fulfill these requirements; however, current technologies are limited to enhancing a single property, leading to the development of high-performance monofunctional ceramics.

The objective of the present talk is introduced to the creation of a new family of advanced ceramics of synergy ceramics based on novel concepts which give rise to the compatibility of diverse properties and the integration of different functions into the same material, the synergistic effect. The progress in ceramics materials from monolithic to synergy ceramics is given in Table 2.

In the present talk, the development of synergy ceramics focusing on the synthesis of new materials, integrated structure development and integrated multifunction will be presented and discussed.

Table 2. Progress in Ceramics Materials



Outline of National Project on Synergy Ceramics (Integrated Inorganic Materials)

43070089C Tokyo KOJI KOZO SEIGYO YUGO MUKI ZAIRYO in English 22 Mar 94 pp 7-9

[Article by Morihiro Kurushima, Agency of Industrial Science and Technology, MITI]

[Text]

1. Background and Objective

In the presence of serious global environmental problems, it has become imperative to make a fast transition from the current technologies into the technologies which save energy and resource and contribute to the reduction of environmental pollution. These new technologies call for the development of high performance materials having better properties with a longer life under more severe operating conditions. Ceramics seem to be promising materials to fulfill these requirements; however, current technologies are limited to enhancing a single property, leading to the development of high-performance monofunctional ceramics.

The objective of this project is the creation of a new family of advanced ceramics (synergy ceramics) based on novel concepts which give rise to the compatibility of diverse properties and the integration of different functions into the same material, the synergistic effect.

2. Project Outline

Characteristics and properties of a given material are closely related to the type and the structure of the constituent elements. These elements have different size and morphology (shape, configuration, distribution, etc.). The size can range from the atomic-molecular scale, through the nano-scale (1/1,000,000 mm) and micro-scale (1/1,000 mm) to the macro-scale (Figure 1). Therefore, control of properties or functions of the materials is exactly control of the composition, size and morphology of their structural elements.

In general, control of the structural elements in ceramics has been limited to one of the above scales (mostly the micro-scale), and while a marked improvement of one specific property (e.g. strength) could be achieved, this approach usually resulted in detriment of another property (e.g. fracture toughness).

By introducing the novel concept of "hyper-organized structure controlling," that is the simultaneous control of structural elements at the diverse scale levels, this project attempts to create synergy ceramics, where diverse properties are made compatible and/or different functions are integrated into the same material (Figures 2 and 3).

3. Research and Development Items

The first stage of the project will be concentrated mainly on the establishment of basic science and technology for hyper-organized structure controlling. Efforts will also be focused on development of fundamental science and technologies for analysis and evaluation.

(1) Processing Science and Technology

Development of essential science and technology for hyper-organized structure controlling, which establish the foundation for the development of synergy ceramics.

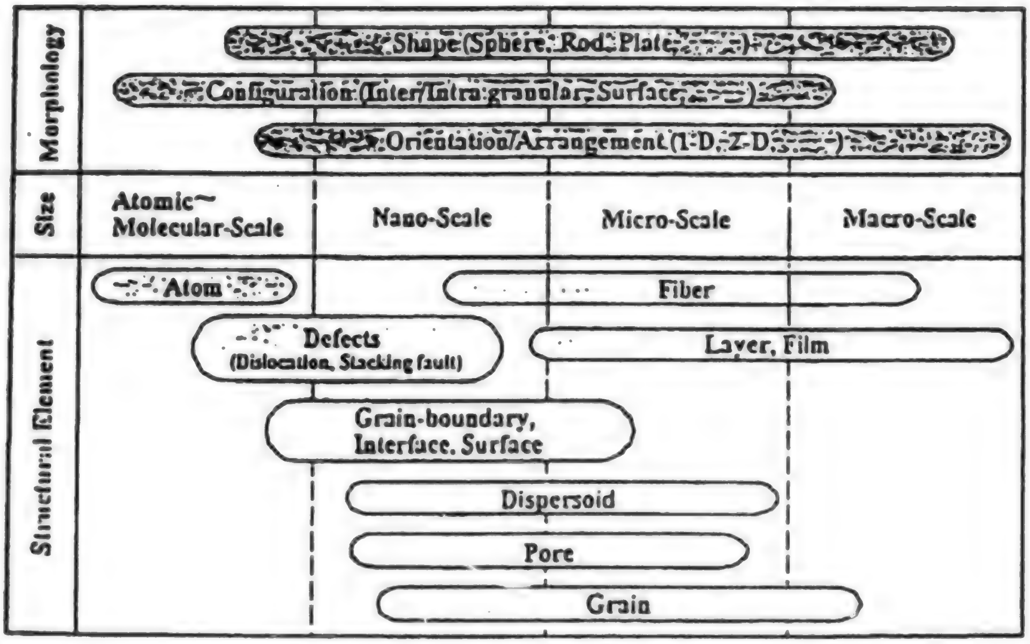
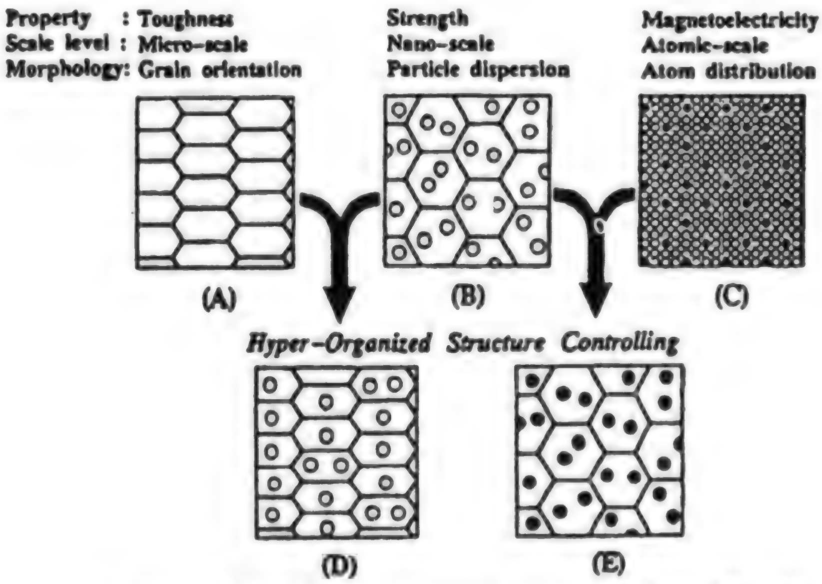


Figure 1. Classification of the Structures



(D): Compatibility of different mechanical properties (e.g. strength and toughness).
(E): Compatibility of mechanical properties and a magnetoelectric function.

Figure 2. A Schematic of Hyper-Organized Structural Control

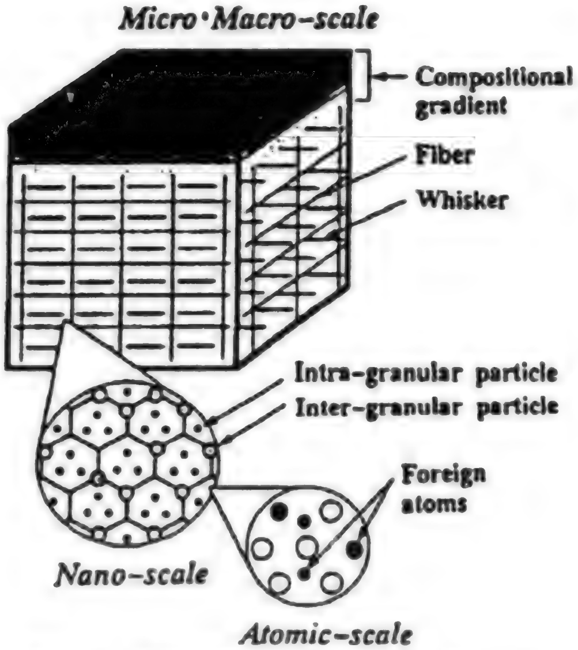


Figure 3. A Typical Structure of Synergy Ceramics

Basic science and technology for hyper-organized structure controlling: Development of new methods for simultaneous control of the morphology and distribution of structural elements at diverse scale levels.

Processing technology for hyper-organized structures: Development of basic processing technology that makes it possible to create new materials with hyper-organized structure.

(2) Analysis and Evaluation Technology

Observation and analysis of properties and modeling of fracture mechanisms of ceramics will be focused on developing fundamental technologies for structural design of the synergy ceramics.

Basic technology for analysis and evaluation: Clarification of the factors responsible for macroscopically observed phenomena associated with mechanical properties.

Technology for material structure design: Development of new technologies including computer simulation of fracture, in-situ observation and analysis of crack propagation, etc.

Evaluation technology: Development of new methods for evaluating properties with small test pieces.

4. Technological Prospect and Field of Application

Taking advantage of the diversity in size, configuration and morphology of structural elements in ceramic materials, innumerable opportunities for the development and creation of synergy ceramics can be envisaged (Figure 4).

(1) Energy-related field

- High-temperature heat exchanger for high-efficiency ceramic gas turbines for coal gasification
- Inter-connector parts for solid oxide fuel cell (SOFC)

(2)Environment-related field

- Exhaust gas filter
- Catalyst carrier for petroleum purification and chemical plants

(3) Others

- Environment-resistant sensors

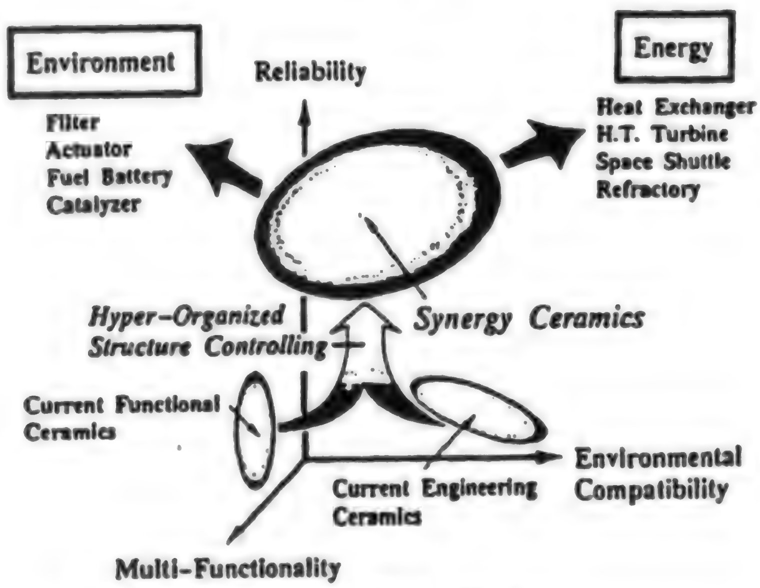
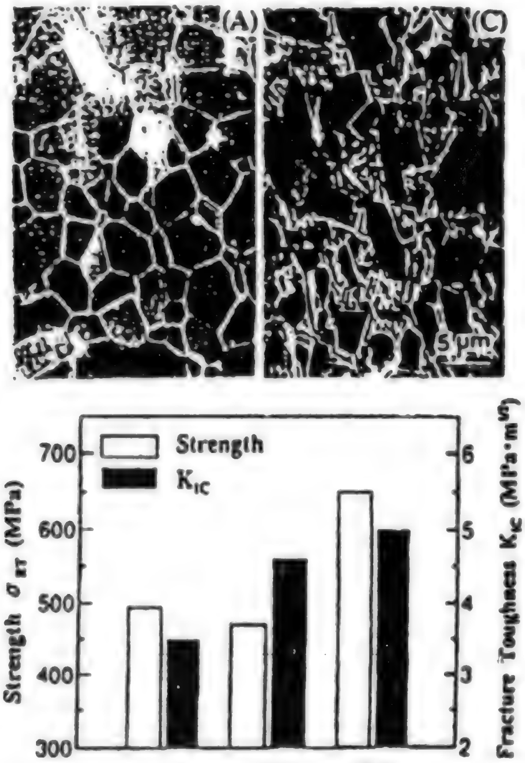


Figure 4. Scope of Synergy Ceramics

5. Leading Research: Current Results

The illustration shows an example where strength and fracture toughness are made compatible with each other through hyper-organized structure control (Figure 5).



(A): High purity Al_2O_3
(B): High purity Al_2O_3 with a small amount of additive
(C): Hyper-organized structure controlling of Al_2O_3

Figure 5. An Example of Hyper-organized Structure Controlling

Novel Structure Controlling of Silicon Nitride and Alumina Ceramics

43070089D Tokyo KOJI KOZO SEIGYO YUGO MUKI ZAIRYO in English 22 Mar 94 p 11

[English abstract of article by Kiyoshi Hirao, Masaki Yasuoka, Manuel E. Brito, and Shuzo Kanzaki, National Industrial Research Institute, Nagoya]

[Text] Silicon nitride and alumina ceramics were prepared based on the new concept for simultaneous control of structural elements at diverse scale levels (hyper-organized structure controlling). The compatibility of diverse mechanical properties in the same materials was experimentally verified. silicon nitride with a morphologically controlled bi-modal microstructure was obtained by the use of rod-like β-Si_3N_4 single crystal particles as seed crystals. The development of a bi-modal microstructure, where the size and distribution of large elongated grains is controlled by seeding, allows improvement of fracture toughness from 6.3 to 8.7 MPa/m$^{1/2}$ while retaining high strength levels of about 1 GPa. Also, a microstructure, where elongated alumina matrix grains and plate-like aluminate ($LaAl_{11}O_{18}$) grains are in-situ developed, was obtained under simultaneous control of nano- and micro-scale structural elements by additions of SiO_2 and La_2O_3. Consequently, both high strength of 620 MPa and high fracture toughness of 6 MPa/m$^{1/2}$ were achieved for the alumina ceramics for the first time. We have demonstrated the possibility that antagonistic mechanical properties, such as high fracture toughness and high strength, can be made compatible within the same material.

Basic Study on Controlled Arrangement of Structural Element

43070089E Tokyo KOJI KOZO SEIGYO YUGO MUKI ZAIRYO in English 22 Mar 94 p 17

[English abstract of article by Kazuo Ueno and Takahiro Inoue, Osaka National Research Institute, Agency of Industrial Science and Technology: Basic Study on Controlled Arrangement of Structural Element: Structural Tailoring of SiC Monofilament/SiC Nano-Particle/Nonoxide Ceramics]

[Text] SiAlON and silicon nitride matrix composites were nano-size SiC particle and SiC monofilament have been fabricated by a layer sticking method. SiAlON matrix composite showed improvements in both fracture resistance (1500 J/m^2) and bending strength (400 MPa), the latter degenerated when reinforced with only SiC fiber. In the Si_3N_4 composite, SiC particle dispersion compensated strength degradation by the fiber incorporation, although it caused a significant loss in fracture resistance. However, the composite had the fracture energy of 960 J/m^2, which is far greater than that of monolithic Si_3N_4 (up to 70 J/m^2).

Verification of Response to Environment

43070089F Tokyo KOJI KOZO SEIGYO YUGO MUKI ZAIRYO in English 22 Mar 94 pp 21, 24-25

[English abstract, table, and graphics of article by Morito Akiyama, Kazuhiro Nonaka, Kazuhisa Shobu, and Tadahiko Watanabe, Kyushu National Industrial Research Institute]

[Text] The electrical properties of PZT was kept sufficiently after bonding to $MoSi_2$-20wt%Mo_2B_5 surface. When cracks were created on the other $MoSi_2$-Mo_2B_5 surface of the layered composite ceramics with a Vickers hardness tester, the voltage vibration of above 250 mV appeared.

C-axis oriented aluminum nitride (AlN) thin films were prepared on polycrystalline $MoSi_2$ substrates by RF-magnetron sputtering in the mixture gases of argon and nitrogen. The morphology of the thin film was a columnar structure with the axis perpendicular to the substrate surface. When the cracks were created on the other $MoSi_2$-Mo_2B_5 surface, the AlN composite ceramics also showed similar results of the PZT.

These results show some new possibilities of developing ceramic materials with self-fracture detection function.

Table 1. Electrical Properties of Samples

Samples	kp	ε	Qm
PZT	0.45	708	207
PZT/inorganic adhesive/$MoSi_2$-Mo_2B_5	0.31	673	19.1
PZT/epoxy adhesive/ $MoSi_2$-Mo_2B_5	0.22	172	16.7

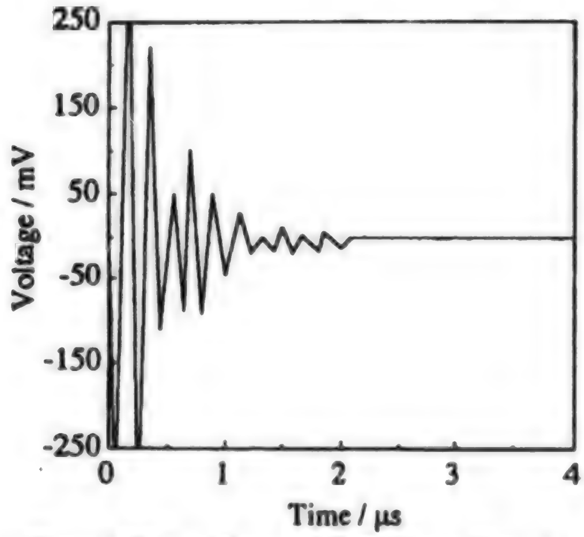


Figure 1. Voltage Change of PZT When a Crack Is Introduced on $MoSi_2$-20wt%Mo_2B_5/Zirconia Adhesive/ PZT Surface

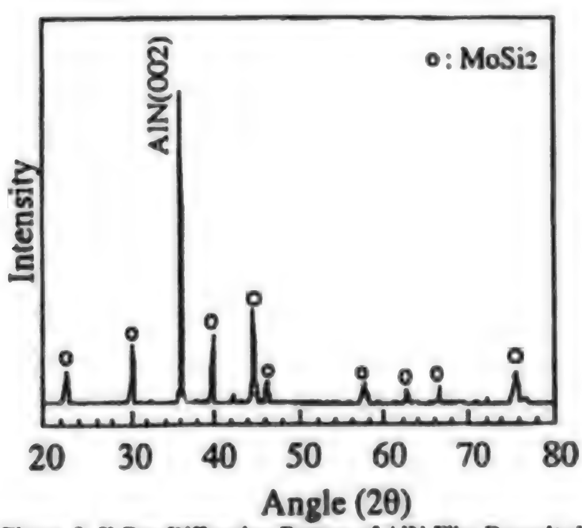


Figure 2. X-Ray Diffraction Pattern of AlN Film Deposited on $MoSi_2$ at 500°C

Figure 3. SEM Micrograph of AlN Film Deposited on $MoSi_2$ at 500°C

Research Study on Integrated Organic Materials

43070089G Tokyo KOJI KOZO SEIGYO YUGO MUKI ZAIRYO in English 22 Mar 94 p 27, 31-32

[English abstract and tables of article by Mitsuo Chigasaki, Japan Fine Ceramics Association]

[Text] The research committee on "Integrated Inorganic Materials" was organized, and the latest trend of the research on new materials has been surveyed laying stress on inorganic composite materials. Preliminary basic research concerning "Material Design and Evaluation for Integrated Inorganic Materials" was carried out at JFCC. The results obtained will be reflected in the National project on Synergy Ceramics.

Table 1. Research Committee on Integrated Inorganic Materials

Chairman: M. Shimada (Professor, Tohoku University)

Members:

S. Hirano (Professor, Nagoya University)

K. Niihara (Professor, Osaka University)

M. Sakai (Professor, Toyahasi University of Technology)

K. Koumoto (Professor, Nagoya University)

T. Kishi (Professor, The University of Tokyo)

H. Tabata (National Industrial Research Institute of Nagoya)

H. Ishikawa (Osaka National Research Institute)

T. Watanabe (Kyushu National Industrial Research Institute)

H. Okada (Japan Fine Ceramics Center)

T. Soma (NGK Insulators, Ltd.)

N. Okumura (Nippon Steel Corporation)

K. Kurata (Ishikawajima-Harima Heavy Industries Co., Ltd.)

M. Nakajima (Denki Enki Kagaku Kogyo, Ltd.)

M. Miyake (Sumitomo Electric Industries, Ltd.)

K. Koga (Kyocera Corporation)

K. Sato (Asahi Glass Co., Ltd.)

I. Hattori (Toshiba Corporation)

M. Sugiyama (Toyota Motor Corporation)

K. Maeda (Hitachi Ltd.)

Y. Matsuo (Matsushita Electric Industrial Co., Ltd.)

Y. Maki (Nissan Motor Co., Ltd.)

M. Suzuki (Chubu Electric Power Co., Incorporated)

Table 2. Technical Committee on Integrated Inorganic Materials

Chairman: M. Shimada (Professor, Tohoku University)

Members:

S. Hirano (Professor, Nagoya University)

K. Niihara (Professor, Osaka University)

S. Kanzaki (National Industrial Research Institute of Nagoya)

K. Ueno (Osaka National Research Institute)

H. Matsubara (Japan Fine Ceramics Center)

T. Soma (NGK Insulators,Ltd.)

S. Koga (Ishikawajima-Harima Heavy Industries Co, Ltd.)

S. Okumiya (Asahi Glass Co., Ltd.)

M. Tsuge (Toshiba Corporation)

T. Kanai (Hitachi Ltd.)

S. Kawashima (Matsushita Electric Industrial Co., Ltd.)

Y. Akimune (Nissan Motor Co., Ltd.)

Material Design and Evaluation for Ceramics Having Integrated Microstructures

43070089H Tokyo KOJI KOZO SEIGYO YUGO MUKI ZAIRYO in English 22 Mar 94 p 33

[English abstract and graphic of article by Hideaki Matsubara, Yuki Iwamoto, Takeshi Mitsuoka, Masayuki Takada, and Hiroshi Kawamoto, Japan Fine Ceramics Center]

[Text] The control of integrated or organized structures in ceramics is expected to be a key technology to develop "synergy ceramics" in which plural functions operates simultaneously. This study has been aimed to clarify the feasibility of such new methods or materials as computer simulation of microstructural development, grain growth control in Si_3N_4, solid solution dispersoid in SiC and fracture detection ceramics using electrical conductivity. These methods or materials bring meaningful results to enable the integrated microstructure control for the synergy ceramics.

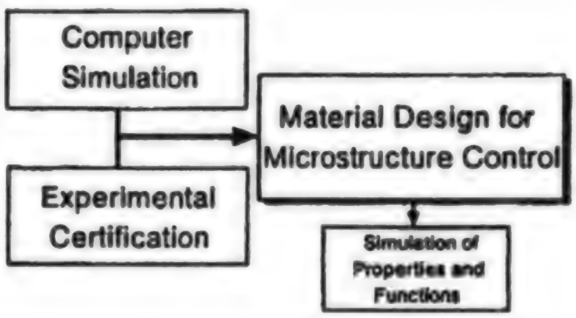


Figure 1. The Diagram of Material Design for Microstructure Control

Abstracts of the 11th NAL Symposium on Aircraft Computational Aerodynamics

Numerical Simulation of Transonic Wind Tunnel Flows About a Fully Configured Model of Aircraft

43070087A Tokyo KOKU UCHU GIJUTSU KENKYUJO in English 10 Jun 94 p 13

[Selected abstracts from the 11th NAL Symposium on Aircraft Computational Aerodynamics (pp 1-248) held 10-11 Jun 1994 in Tokyo, sponsored by the National Aerospace Laboratory; English abstract of article by Yoko Takakura, Fujitsu Ltd., and Satoru Ogawa and Yasuhiro Wada, National Aerospace Laboratory]

[Text] A series of trials to numerically analyze NAL transonic wind-tunnel flows about a fully configured model of aircraft, ONERA-M5, has been performed to investigate the reliability of numerical computations, and in this time the computational region within the wind tunnel has been enlarged. To realize computations of wind-tunnel flows about a complicated configuration, a multi-domain technique and a model of outflow through the perforated wall of the transonic wind-tunnel are used. As a result it is known that this trial is successful since the computed pressure, lift and drag coefficients agree well with experimental ones.

An Unstructured Navier-Stokes Solver UG3

43070087B Tokyo KOKU UCHU GIJUTSU KENKYUJO in English 10 Jun 94 p 25

[English abstract of article by Eiji Shima, Gifu Technical Institute, Kawasaki Heavy Industries, Ltd.]

[Text] This paper presents the algolysum and numerical examples of a three-dimensional unstructured Navier-Stokes solver UG3 (unstructured grid 3D). UG3 is an extension of an upwind scheme on structured grids and keeps accuracy and efficiency of a structured grid's method as much as possible.

UG3 uses a cell centered finite volume method with MUSCL high resolution upwind scheme, and an implicit time integration by the multicolor Gauss-Seidel iterative solver for a large matrix. In order to extend the MUSCL scheme to unstructured grids, the NUM (normalized unstructured mesh) method is developed. This satisfies almost monotonisity even in distorted mesh and is as simple as a structured grids method.

UG3 needs 2 or 3 times larger computational time and memory than a structured grids method on identical grids. This deficiency can be overcome by using fewer grid points utilizing the topological flexibility of unstructured grids method.

Role of Computational Fluid Dynamics in Aeronautical Engineering (II): Trial To Apply Multi-Grid Scheme to Multi-Block Method

43070087C Tokyo KOKU UCHU GIJUTSU KENKYUJO in English 10 Jun 94 p 41

[English abstract of article by Tomohiro Handa and Eiji Sima, Giru Technical Institute, Kawasaki Heavy Industries, Ltd.]

[Text] The multi-grid scheme was applied to the multi-block method which calculates inviscid or viscous flow. We got three times faster convergence with the same accuracy than no multi-grid scheme for both inviscid and viscous flow in simple test cases. More complicated problems, which are inviscid and viscous supersonic flow around SST, were solved using the multi-blocks and multi-grid method, and we got 2 or 3 times faster convergence gain.

Numerical Analysis on Wing/Nacelle Interference Using Overlapped Grid Method

43070087D Tokyo KOKU UCHU GIJUTSU KENKYUJO in English 10 Jun 94 p 47

[English abstract of article by Yasuhiro Tani, Fuji Heavy Industries, Ltd., and Kanichi Amano, Japan Aircraft Development Corp.]

[Text] A numerical study was carried out on wing/nacelle interference for transonic transports. To reduce the interference drag, some shapes of small wings, liplets, were designed. A liplet is a wing installed on both sides of the pylon just downstream of the upper part of the nacelle fan cowl trailing edge, to control the flow in the interference region. Three-dimensional Euler calculation was carried out at transonic cruise condition. A flow analysis code using an overlapped grid method was developed and successfully applied to calculate the flow field around the wing-nacelle/liplet configuration. The result shows the effect of the liplet to the wing surface pressure, and indicates the overlapped grid method is efficient to analyze such a complicated geometry.

Compendium of Results Flow Analysis Around ONERA Model M5 Configuration

43070087E Tokyo KOKU UCHU GIJUTSU KENKYUJO in English 10 Jun 94 p 56

[English abstract of article by Jiro Nakamichi, National Aerospace Laboratory]

[Text] Compendium of results of three-dimensional problem: Flow analysis around ONERA M5 configuration is given. All of the submitted computation results were shown on the respective figures to see the differences between the computed results and experimental data. In Problem A: flow analysis with free stream condition of Mach number, 0.84, $\alpha = -1^\circ$, Reynolds number, 1×10^6, with free transition condition and Problem B: flow analysis with free stream condition of

Mach number, 0.84, $\alpha = -1°$, Reynolds number, 6×10^7 with fully turbulent conditions, the pressure distributions and Cp contours on the lifting surface and the fuselage were compared. Experimental data with Reynolds number 1×10^6 were also shown. In Problem A, the computed transition lines of the main wing surface were compared. In Problem C: computation of aerodynamic characteristics of the model aircraft, the C_L-α, C_L -C_D and C_L - C_M curves were shown in comparison with experimental data.

The factors leading to the present results were discussed and necessary future improvement were also discussed.

Transition Prediction Using the RNG Based Algebraic Turbulence Model

43070087F Tokyo KOKU UCHU GIJUTSU KENKYUJO in English 10 Jun 94 p 61

[English abstract of article by Andi Eka Sakya and Yoshiaki Nakamura, Department of Aeronautical Engineering, Nagoya University]

[Text] A new length scale for flow with pressure gradient is proposed in the RNG algebraic turbulence model. The dissipation rate is modeled, so that the equation for eddy viscosity takes the cubic form. The model shows the continuity of eddy viscosity near the wall. This model was applied to predict transition location for flows at pressure gradient. The characteristics of the predicted transition well agree with the experimental and empirical data.

Analysis of Unstarted Flutter in Supersonic Cascade

43070087G Tokyo KOKU UCHU GIJUTSU KENKYUJO in English 10 Jun 94 p 67

[English abstract of article by Hirofumi Doi, Graduate School, University of Tokyo, and Shojiro Kaji, Department of Aeronautics and Astronautics, University of Tokyo]

[Text] In the case of unstarted supersonic flutter in a cascade, the aerodynamic instability of the blade motion is affected by shock motion, and the occurrence of bending flutter is predicted. In the present paper, Euler equations are solved using the explicit TVD scheme in finite-difference formulation. The computational domain is limited to six channels and the center blade vibrates. Analysis is made by superposition of the computed unsteady components on the surface of each blade, considering the interblade phase angle. The results show that the occurrence of bending flutter is predicted when negative aerodynamic dumping force generated by shock motions acts on the suction surface for negative interblade phase angle.

Numerical Analysis of Wake Flow Behind Hypersonic Vehicle

43070087H Tokyo KOKU UCHU GIJUTSU KENKYUJO in English 10 Jun 94 p 73

[English abstract of article by Dae Sung Ro and Kazuhiko Ogawa, Graduate School of Science and Technology, Kobe University, and Takeyoshi Kimura, Department of Mechanical Engineering, Kobe University]

[Text] The flow field behind blunt based bodies was investigated with numerical simulation at a nominal Mach number of 5.7, 8.5, 10.0 over a range of Reynolds numbers from 50,000 to 335,000 based on the body length.

The finite volume formulation of Van Leer's flux vector splitting upwind scheme, in generalized coordinates, was used to solve thin-layer approximation of the Navier-Stokes equations for a hypersonic laminar flow. An implicit approximate factorization and MUSCL (monatomic upstream-centered scheme for conservation laws) scheme with flux limiter were used to acquire high order spatial accuracy.

Special attention was given to the base-pressure, static-pressure along the center-line, trailing shock wave, the location of separation point and vortical flow in the recirculation region. The result of a numerical simulation quite agreed with that of a visualization experiment of a shockwave.

Dynamic, Numerical Simulations of Restart Phenomenon in Scramjet Intake

43070087I Tokyo KOKU UCHU GIJUTSU KENKYUJO in English 10 Jun 94 p 79

[English abstract of article by Tadashi Ishikawa and Hiroshi Wakai, Fuji Heavy Industries Co., Ltd., and Toyosei Yamauchi, Subaru Research Center Co., Ltd.]

[Text] The inner flow fields of the scramjet intake model are simulated numerically by two-dimensional Euler equations using an implicit finite difference scheme. For these simulations, the numerical scheme based on Chakravarthy-Osher's type TVD formulations is improved for both multi-grid and moving-grid application.

To investigate the methods of recovery from unstart conditions in scramjet, at first, the dynamic and numerical simulations were conducted from steady condition to unstart condition using moving-grid.

Numerical Simulation of Nozzle Flow of Hypersonic Wind Tunnel

43070087J Tokyo KOKU UCHU GIJUTSU KENKYUJO in English 10 Jun 94 p 85

[English abstract of article by Takashi Kawashima, Hidenori Yoshida, and Kiromitsu Kiyose, Akashi Technical Institute, Kawasaki Heavy Industries, Ltd.]

[Text] Toward the 21st century, some hypersonic wind tunnels for development of space planes and supersonic transports are under construction and planned in our country. For designing these wind tunnels, it is indispensable to make use of CFD technology.

This paper describes a numerical simulation of the nozzle flow of a hypersonic wind tunnel. The flow through the hypersonic axisymmetric nozzle with exit Mach number 7.0, which was installed in the hypersonic wind tunnel of the National Aerospace Laboratory (NAL), was calculated by using three-dimensional Navier-Stokes codes with q -ω model of turbulence by T.J. Coakley. The calculated results were compared with the experimental data, which had also been obtained by NAL, on the flow distributions at nozzle exit. Comparison with experiment and calculation shows a reasonable agreement. The effect of wall conditions such as adiabatic wall or isothermal wall upon the exit flow distribution was also investigated by numerical simulation.

Numerical Analysis of Bubbly Flow Through a Converging-Diverging Nozzle

43070087K Tokyo KOKU UCHU GIJUTSU KENKYUJO in English 10 Jun 94 p 91

[English abstract of article by Ryuji Ishii and Shigeaki Murata, Department of Aeronautical Engineering, Kyoto University]

[Text] Characteristics of bubbly flow through a converging-diverging nozzle are investigated theoretically and numerically. First, a new model equation of motion governing a dispersed bubble phase is proposed. This is compared in detail with those proposed previously. Next, hyperbolicity of the resultant system of governing equations for the bubbly flow is investigated in detail. Numerical simulation of bubbly flows through a converging-diverging nozzle are carried out by using the proposed system of model equations. In order to check the validity of t numerical results and then the proposed system, they are compared with the experiments which were performed in a water-nitrogen blow-down facility.

Aerodynamic Design of Space Vehicle Using Numerical Simulation Technique

43070087L Tokyo KOKU UCHU GIJUTSU KENKYUJO in English 10 Jun 94 p 97

[English abstract of article by Yukimitsu Yamamoto, Yasuhiro Wada, and Susumu Takanshi, National Aerospace Laboratory, and Mitsuo Ishiguro, Mitsubishi Heavy Industries, Ltd.]

[Text] Optimization of the aerodynamic configuration of a space vehicle (HOPE) is conducted by using several numerical simulation codes in the transonic and hypersonic speed ranges. Design requirements are set on the longitudinal aerodynamic characteristics in the transonic speed and the aerodynamic heat characteristics in the hypersonic speed. This paper describes the procedure of the optimization of aerodynamic configurations by using the numerical simulation technique as an effective design tool. Analysis shows the good aerodynamic characteristics of the final configuration and hence validity of our optimization.

Numerical Analysis of Scramjet Nozzle Flow (Under Absence of Reaction)

43070087M Tokyo KOKU UCHU GIJUTSU KENKYUJO in English 10 Jun 94 p 103

[English abstract of article by Tomiko Ishiguro, Ryoji Takaki, Tohru Mitani, and Tetsuo Hiraiwa, National Aerospace Laboratory]

[Text] A proposal of numerical procedure is given for nonreacting flows of ideal N_2 gas through scramjet nozzles by using a multi-grid method and the three-dimensional Navier-Stokes equations with the Baldwin-Lomax algebraic eddy viscosity model. Here trailing edges of side-walls are assumed not to be perpendicular to a streamwise axis. The computational results of nozzle internal flow such as static pressure, skin friction coefficient, heat flux, thrust, etc., are compared with experimental data for the under-expansion case with no effect of ambient condition. Both of them agree with uncertainties of 2-4% for the thrust of nozzle. Flowfields obtained by computations under various ambient conditions (flow of $M_\infty = 6$ or still gas with pressure of under-or over-expansion) are also investigated.

Numerical Simulation of Hypersonic Flight Experiment Vehicle

43070087N Tokyo KOKU UCHU GIJUTSU KENKYUJO in English 10 Jun 94 p 109

[English abstract of article by Yukimitsu Yamamoto, National Aerospace Laboratory, and Minako Yoshioka, Fujitsu Ltd.]

[Text] Hypersonic aerodynamic characteristics of the Hypersonic Flight Vehicle (HYFLEX) vehicle were investigated by numerical simulations using Navier-Stokes CFD code of NAL. Numerical results were compared with experimental data obtained at hypersonic wind tunnel at NAL. In order to investigate real flight aerodynamic characteristics, numerical calculations corresponding to the flight conditions suffering from maximum aerothermodynamic heating were also made and the differences between flight and experimental conditions were considered.

Direct Simulation of Rarefied Nitrogen Gas Flows Using SICS Model

43070087O Tokyo KOKU UCHU GIJUTSU KENKYUJO in English 10 Jun 94 p 115

[English abstract of article by Katsuhisa Koura and Mikinari Takahira, Aerodynamics Division, National Aerospace Laboratory]

[Text] The statistical inelastic cross section (SICS(D)) model developed for the Monte Carlo simulation of molecules with discrete rotational energy is used for the direct simulation of rarefied nitrogen gases contained between two parallel plates at a small temperature difference and hypersonic rarefied nitrogen gas flows around a circular cylinder. The density distributions between the plates are in reasonable agreement with the experimental results for the reflection

coefficient α = 0.60-0.76. The rotational distribution in front of the cylinder shows the bimodal Boltzmann distribution consistent with the measurement.

Monte Carlo Simulation of Supersonic Free Jet

43070087P Tokyo KOKU UCHU GIJUTSU KENKYUJO in English 10 Jun 94 p 121

[English abstract of article by Susumu Teramoto, Graduate School, University of Tokyo, and Toshio Nagashima, Department of Aeronautics and Astronautics, University of Tokyo]

[Text] Numerical solutions of direct simulation Monte Carlo (DSMC) method are obtained for axisymmetric supersonic free jet in the transition region ($Kn_{\infty} = 0.1$). The effects of parameters such as the number density of simulation particles and cell division upon the solution are examined, and pitot pressure calculated from the numerical solution is compared with the experimental data obtained by Askenas and Sherman.

Direct Simulation of Fuel Combustion in Supersonic Shear Flow

43070087Q Tokyo KOKU UCHU GIJUTSU KENKYUJO in English 10 Jun 94 p 127

[English abstract of article by S. Obata, Graduate School, University of Tokyo, and T. Nagashima, Department of Aeronautics and Astronautics, University of Tokyo]

[Text] The direct simulation Monte Carlo (DSMC) method based on the Boltzmann equation has been employed to analyze fuel gas mixing and reaction in two-dimensional supersonic shear flow which is formed due to the meeting at a thin plate (lip) edge of two parallel flows, a supersonic air stream and a sonic hydrogen gas flow. The influence of hydrogen gas temperature upon the mixing within shear layer has been clarified and by applying 16 reaction system the relationship between the mixing and the endo/exothermic reaction region has been analyzed to reveal the details of the ignition process.

Numerical Analysis of Supersonic Combustion Flow

43070087R Tokyo KOKU UCHU GIJUTSU KENKYUJO in English 10 Jun 94 p 133

[English abstract of article by Makoto Nishiuchi, Mitsubishi Heavy Industries, Ltd.]

[Text] Interest in chemically reacting flow analysis codes has been raised. These codes have some difficulties, such as variable time scale. We have been developing two-dimensional chemically reacting flow analysis code for air-hydrogen combustion flow. In our method, chemical reaction is fully coupled with Navier-Stokes flow solver. At first, to validate our code, the two-dimensional numerical solution was compared with the experiment data. Then we applied this code to practical configuration, such as scramjet with intake, step, fuel injection, and nozzle.

Numerical Simulation of Arc Wind Tunnel Flow Using Navier-Stokes Equations

43070087S Tokyo KOKU UCHU GIJUTSU KENKYUJO in English 10 Jun 94 p 139

[English abstract of article by Ryoji Takaki, Yasuhiro Wada, and Yasuo Watanabe, National Aerospace Laboratory]

[Text] A numerical analysis of thermochemical nonequilibrium viscous flow is made for the arc wind tunnel at NAL. The calculation is carried out with a Harten-Yee type TVD scheme and LU-SSOR implicit method, using finite-rate seven species chemical reactions and Park's two-temperature model in order to take account of nonequilibrium thermochemistry. In this calculation, three grids are used: nozzle part with arc heater, test section, and around a test piece. To simulate different kinds of nozzle flow such as over expansion, under expansion, and normal expansion, four cases with various test section pressures are analyzed. The effects of the expansion type on the heat flux distribution on the surface of the test piece and flow states are presented.

Numerical Simulations on Irregular Reflection of Shock Waves

43070087T Tokyo KOKU UCHU GIJUTSU KENKYUJO in English 10 Jun 94 p 151

[English abstract of article by Yoshiro Miura and Fumio Higasino, Department of Mechanical Systems Engineering, Tokyo Noko University, and Satoru Ogawa, National Aerospace Laboratory]

[Text] This paper reports the results of numerical computations on the oblique reflection of weak shock waves over a wedge. To check the numerical resolution of the scheme, the results obtained by the Godunov scheme were compared with those from the TVD schemes. The results show that when incident shock strengths become weak, the difference between the two schemes becomes significant. For comparatively strong shocks the results computed by the Godunov scheme coincide with those given by the TVD scheme. In general the TVD scheme captured shock discontinuities as well as the slipstream. To clarify the physical phenomena of the von Neumann reflection, entropy profiles behind the curved shock front were calculated. The condition of the von Neumann reflection for weak shock waves was explained quantitatively by assuming quasi stationary shock reflection.

Numerical Simulations of Unsteady Aerodynamic Heating Phenomena on Shock Wave Reflection Including Vibrational Equilibrium

43070087U Tokyo KOKU UCHU GIJUTSU KENKYUJO in English 10 Jun 94 p 157

[English abstract of article by Shigeru Aso, Ken-ichi Ohyama, Toshi Fujiwara, and Masanori Yahashi]

[Text] Thin-layer Navier-Stokes equations have been solved in order to investigate unsteady aerodynamic

heating phenomena induced by the shock impingement on a ramp surface with emphasis on high-temperature effects. Especially the effect of energy transfer between translational energy and vibrational energy is investigated carefully. The results show that the vibrational energy has a quite important role in unsteady aerodynamic heating phenomena at high temperature.

Structure and Drag of Laminar Flow Over Wavy Walls

43070087V Tokyo KOKU UCHU GIJUTSU KENKYUJO in English 10 Jun 94 p 163

[English abstract of article by Takashi Taniguchi and Sigeo Tsutaki, Graduate School, Faculty of Engineering, Chiba University and Nobuhide Nishikawa and Yoshiya Itakura, Department of Mechanical Engineering, Chiba University]

[Text] In the present paper a numerical study is conducted for viscous two-dimensional incompressible flow over wavy walls. The employed method is an application of the boundary fitted coordinate for ψ-ω method. In the ψ-ω method the finite differencing of the convection terms in Navier-Stokes equations employs the Kawamura-Kawahura scheme, and the time-integration is performed with the M.O.L. method.

The model problem is the flow past over wavy walls. We consider a sequential protuberance of height 2a and wavelength λ. In the numerical experiments, $2a/\lambda = 0.1$, 0.2, and 0.4, and Reynolds numbers Re-1000, 2000, 3000, and 4000. The reason for choosing this problem is that, by suitable choice of $2a/\lambda$ and Reynolds number, it is possible to examine flows with different separation patterns. It is the flow past over wavy walls, with separation and reattachment points not known a priori. The flow features of particular concern, both from numerical as well as physical viewpoints, are the adjustment of the initially fully developed flow to a spatially periodic condition and, for specific amplitudes, the occurrence of repeated separation bubbles. Such configurations are of interest in drag reduction and heat-transfer enhancement. In the application of CFD for calls with sequential protuberances, the effect of alternating favorable and adverse pressure gradients should be analyzed, which correspond to convex and concave surface curvatures on the wall.

Active Control of Vortex Shedding Frequency by Jet

43070087W Tokyo KOKU UCHU GIJUTSU KENKYUJO in English 10 Jun 94 p 169

[English abstract of article by Norio Arai and Keusuke Shimada, Tokyo Noko University]

[Text] The control method of the vortex shedding frequency by a jet is investigated numerically, in which it is spouted out from the rear surface of the body. Especially, emphasis is put on the control effect of vortex shedding frequency and of hydraulic forces. The three-dimensional Navier-Stokes equations are solved. The Reynolds number is 10,000. Results are summarized:

(1) When the jet speed exceeds some values, the body oscillation can be prevented effectively.

(2) The three-dimensionality of the flow has a strong influence on the hydraulic forces.

(3) The control effect of the jet is that the mutual interaction between the wake and the jet increases the length of the vortex formation region and decreases the hydraulic forces.

Numerical Simulation of Laminar Flow Between Concentric Rotating Cylinders

43070087X Tokyo KOKU UCHU GIJUTSU KENKYUJO in English 10 Jun 94 p 175

[English abstract of article by Hiroshi Ishigaki, Kakuda Research Center, National Aerospace Laboratory]

[Text] A numerical simulation is made for laminar flow between concentric rotating cylinders with stationary end walls. When the inner-cylinder rotates, Taylor vortices develop in addition to secondary flow vortices. The developments of flow pattern are shown for aspect ratio of 2, 3 and 15.

Performance Evaluation on NWT With CFD Programs

43070087Y Tokyo KOKU UCHU GIJUTSU KENKYUJO in English 10 Jun 94 p 179

[English abstract of article by Takashi Nakamura, Masahiro Yoshida, and Masahiro Fukuda, National Aerospace Laboratory, and Takeo Murase and Tatsuya Matsuzaki, Fujitsu Ltd.]

[Text] The National Aerospace Laboratory and Fujitsu Ltd. have jointly developed a parallel vector computer called "numerical wind tunnel" (NWT) for the advancement of computational fluid dynamics in the field of aeronautics and space technology. The NWT is composed of 140 processing elements connected with a crossbar network. Its total performance is 236 gigaflops and aggregate memory capacity is 35 gigabytes. Evaluation results with a three-dimensional CFD program show the performance of 116 gigaflops on 140 PEs, and sustain the performance about 90% from 2 to 64 PEs, moreover 80% on 128 PEs.

Three-Dimensional Numerical Analysis of Injection Into Supersonic Flow

43070087Z Tokyo KOKU UCHU GIJUTSU KENKYUJO in English 10 Jun 94 p

[English abstract of article by Kazuhiko Yokota, Graduate School, University of Tokyo, and Shojiro Kaji, Department of Aeronautics and Astronautics, University of Tokyo]

[Text] The supersonic flow and mixing fields with a perpendicular air injection from a finite length slit are

investigated by solving the three-dimensional full Navier-Stokes equations and the two chemical species conservative equations. As the turbulent model, the subgrid scale model of the large eddy simulation is employed. The Yee's type upwind total variation diminishing scheme is applied for the convective terms of the governing equations. The dissipation terms are evaluated by the central difference. The time integration is performed by using the lower-upper factored implicit method.

Two slit angle cases of 90° and 45° are treated. The experimental measurements are performed in order to confirm the reliability of the three-dimensional numerical code. The numerical results are compared with the experimental ones as regards the pitot pressure distributions. The numerical results fairly agree with the experimental data both qualitatively and quantitatively. In the numerical simulation, the main flow air and the injected air are treated as the different species, so the mixing fields can be examined. From the results in case of the 90° slit angle, even though the injection slit is long enough, the flow and mixing fields are rather three-dimensional because of the existence of both side ends. Furthermore, in case of the 45° slit angle, the flow and mixing fields are more three-dimensional, and the mixing is enhanced. All the results show that a part of the main flow which gets into the downstream side of the list influences on the mixing augmentation in the higher order than the vortex flow in the vicinity of the slit ends.

Study on Mixing Enhancement in Supersonic Flow Fields With Secondary Transverse Injection

43070087 Tokyo KOKU UCHU GIJUTSU KENKYUJO in English 10 Jun 94 p 191

[English abstract of article by Yoshiyuki Yamane, Toshiro Fujimori, and Yasunori Ando, Ishikawajima Heavy Industries Co., Ltd.; Shigeru Aso, Shozo Maekawa, and Michiaki Tannou, Kyushu University; and Masahiro Fukuda, National Aerospace Laboratory]

[Text] A fundamental characteristic of supersonic mixing field with transverse injection is examined by numerical and experimental studies. A sonic jet is injected perpendicularly into supersonic flow (M=4) from a single hole on flat plate. The pitot pressure distribution is measured three-dimensionally. Numerical simulation is conducted in the flow field, and is compared with experimental data. It is shown that the present investigation is verified quantitatively and has a good reliability.

On the basis of numerical and experimental results, phenomena of the present flow field are discussed. It is observed that the counter-rotating vortex pair which rolls up from near the flat plate is generated and the mixing occurs as a result of entraining by these vortexes. Jet core location is estimated from pitot pressure distribution.

LCD Applications Strategy for Each Company

94FE0725A Tokyo SEMICONDUCTOR WORLD in Japanese Jun 94 pp 19-23

[Text] The EDEX '94 electronics display exhibit sponsored by the EIAJ (Electronic Industry Association of Japan) was held April 6-8 in Pacifico Yokohoma, Kanagawa. Twenty-three companies participated in the exhibit, and attendance totaled 14,977 (4,180 on April 6; 5,357 on the 7th; and 5,440 on the 8th). This report covers the LCD applications seen in the exhibits and the measures being taken to reduce the cost of LCD panels.

Applications Focus on Notebook PCs, Audio/Visual and Multimedia Equipment

Most of the exhibits on display focused on liquid crystal displays. Fujitsu exhibited a plasma display, Sharp and Fujitsu featured light emitting diodes, and HItachi Ltd. and Sony exhibited CRTs. However, visitor interest centered on the LCD exhibits.

All of the LCD exhibitors emphasized the application of LCDs in notebook personal computers. In addition, audio/visual equipment and amusement applications were cited, with eventual applications possible in multimedia and PDA (portable data terminal) equipment.

Sharp is the lead-off company involved in the PDA. It displayed a 5" color, reflective-type TFT-LCD. It is a four-color LCD (white, black, cyan, and red) with 240 x 340 x 2 (CR) pixels; viewing angle is 100° both left/right and upper/lower, and power consumption is 50mW. The mass production schedule and price have not yet been determined. In addition, Sharp plans to use color TFT-LCDs in high-end notebook-type computers, office automation equipment and automobile televisions; color STN-LCDs will be used in mid-level notebook-type computers and video games. To make up for the deficient supply of TFTs, Sharp pans to improve the performance of the STN-LCD. Applications for the color TFT-LCD itself were also clarified by Sharp. A 5.5" color TFT-LCD for use in automobile television and a lightweight (220g) 6.4" color TFT-LCD panel were new products on display at the exhibit.

To respond to the increasing demand for color TFT-LCDs, Sharp began building a new plant in January 1994 in Taki, Mie. The first phase of the plant will be completed in January 1995, with an equipment investment of 53 billion yen. Production in fiscal '95 will be 100,000 panels per month, based on the 10" size. There are plans to produce a full-color TFT-LCD larger than the 10" size for high-end personal computers and workstations, as well as high quality televisions.

NEC exhibited the color TFT-LCD exclusively. The conventional 4096 color type will be for mid-level notebook computers. At the same time, an analog full-color type has been added to the product line-up. Setting forth a "natural color" concept, NEC plans to use the analog full-color panel in high-end notebook computers, workstations, and other new consumer applications such as flat-panel televisions. 9.4" and 13" versions of this type of panel were displayed. The 9.4" panel currently has a yield of 70%, with 80% targeted for the future. The 13" panel, which was announced in 1993, is currently being produced at 200 units per month, and yield is 50%.

With regard to sales, the rate of external sales, which is currently at 30%, will be increased to 50% in fiscal '95. The chief destination for supply will be personal computer manufacturing companies in Taiwan. It was rumored at one time that NEC would supply panels to Apple Computer and Compaq Computer. However, no agreement was reached with Apple regarding screen size, and talks have ceased. Although an agreement on screen size was reached with Compaq, NEC cannot commit to the desired supply amount, and there is a strong possibility that these talks will also break down.

Although NEC's LCD production base is at NEC Kagoshima, production will also take place at NEC Akita in 1995. As of March 1994, production at Kagoshima was 40,000 panels per month (based on the 9.4" size) from its first and second-phase production lines. In June 1994, production of the second-phase line will be increased to 60,000 panels per month; and in March 1995, NEC Akita will start up at 50,000 panels per month. All totaled, this will establish a monthly production rate of 150,000 panels in March 1995. Even so, this will not be the upper limit, since these figures assume that only the second-phase production line in Kagoshima and half of the building in Akita are being utilized. Production will increase even further in the future. A decision will be made in the latter half of 1994 regarding which of these two facilities will be expanded first.

Toshiba does not plan to focus on general applications. Instead, it will supply panels to meet specific user needs in line with the market trend. Toshiba displayed a 14" color TFT-LCD at the exhibit for reference. This panel, which drew the attention of many, has 1152 x 900 pixels a viewing angle of 100° in both upper/lower and left/right directions, and can be used in CAD workstations. Eight inch and 4" reflective monochrome TN-LCDs were also exhibited. Power consumption by the 8" panel is 0.4W; for the 4" panel, it is 0.2W. Brightness is 50cd/m^2. The 4" and 8" panels can be used in PDA units.

Hitachi plans to focus on notebook computer applications. It will produce TFT-LCD for high-end products and STN-LCD for mid-level and low-end products. Hitachi displayed an 11" color TFT-LCD and a 10.3" color STN-LCD at the exhibit. Development of a 64 color gradient TFT-LCD is continuing, and samples of the panel will be shipped in December 1994. Hitachi also exhibited a 26-color 10.4" TFT for reference. For PDA applications, there was a 512-color 5.7" STN-LCD on display. Hitachi is currently developing a color version of a reflective-type LCD for PDAs. Once this panel is enlarged, it can also be used in notebook computers.

Hoshiden also emphasized notebook computer applications. It is planning to use full-color TFT-LCD in high-end products involving multimedia equipment. The main differences between Hoshiden's panels and those made by others are Hoshiden's wider viewing angle and lower reflectance. Nine inch and 7" full-color TFT-LCDs with viewing angles of 80° upper/lower and 120° left/right were exhibited. With regard to lower reflectance, a 512-color TFT-LCD with a reflectance of 1% or less was on display. Visitors were impressed by the quality when viewed side by side next to conventional panels. A reflective-type monochrome STN-LCD for PDA and sub-notebook type computers was also displayed. Hoshiden is also considering developing a color version of the reflective-type STN-LCD.

Sanyo Electric plans to produce 3" through 6" color TFT-LCDs for portable televisions, VTR/TV combos, video games, and PDAs. Sanyo has established mass production of 6" and smaller TFT-LCD panels and has also produced a 13" color TFT-LCD at the experimental level. However, there are reportedly no plans to mass produce color TFT-LCD panels 10" or larger (for notebook computers) due to cost, yield, and internal issues. The company will produce color STN-LCD panels at its Tottori plant for use in notebook computers.

Sanyo will respond to future demand for multicolor gradient LCDs for notebook computers with independently developed multicolor gradient LSI. This LSI can convert 16 color gradient to 64 color. Response from other companies has also been favorable. Although Sanyo has no current plans to become involved in reflective-type TFt-LCD for PDAs, this could possibly happen in the future once the screen size settles down to about 5".

Seiko Epson also envisions applications in portable televisions and automobile TVs. It is therefore producing super MIM-LCDs ranging in size from 2.5" to 4.5". Although the company is considering a 10" color super MIM-LCD for notebook computers, it is proceeding with caution due to the stiff competition among TFt-LCDs and because the cost advantage associated with the MIM would be lost if a larger screen size was produced. For PDA applications, Seiko-Epson exhibited a reflective-type 4.5" monochrome MIM-LCD. The company will continue to develop and produce poly-Si TFT-LCD for viewfinders, as it has in the past.

Kyocera exhibited STN-LCD exclusively. It is producing a 9.4" color STN-LCD for notebook computers. Production of this type of panel is reportedly 20,000 per month. Although STN-LCD has lower definition and response rate than TFT-LCD, Kyocera is developing a panel that has the same resolution as SVGA. An AA-LCD is also being developed for moving picture processing, and will be announced formally in the near future.

Fujitsu, a latecomer in LCD production, has set out to distinguish itself from other companies by targeting multimedia applications. Picture quality attracted the attention of visitors, who viewed a front-projection type, full-color TFT-LCD; a 1677-color 10.4" color TFT-LCD; and a 25" multipanel LCD. With regard to color TFT-LCDs for notebook computers, Fujitsu feels that although the quantity will be great, the focus will center on multimedia applications. Fujitsu's production base for LCDs is in Yonago, Tottori, where operations started in March 1994. The line currently produces 10" panels, two per substrate, but will shift to a four-per-substrate system in 1996.

Sony is producing poly-Si TFT-LCD for viewfinders, and also exhibited a 10.4" color TFt-LCD monitor. The panels are procured externally, and NTSC and PAL video signals can be displayed at a resolution equal to VGA and Macintosh. These will mainly be supplied for industrial applications such as in aircraft monitors.

As mentioned above, many manufacturing companies are focusing on notebook computer applications for LCDs. There are many companies competing in the same market, and some companies are expressing concern. Mr. Y. Tadano of the Nomura General Research Center/Industrial Technology Group presented a lecture at Electronics Display Forum '94 (which was held in conjunction with EDEX '94) entitled "Developing Applications for FPD".

Mr. Tadano estimates that production capacity for 8.4" and larger TFT-LCD, and for color STN-LCDs will be about 6 million panels per year in 1994, about 14 million panels in 1995, and about 16.5 million million in 1996. Considering the market for notebook computers and word processors between 1994 and 1996, supply will become balanced if the growth rate is 20%, but if the growth rate is 10%, a surplus of panels could occur as early as 1995. Tadano claims that new markets are therefore urgently needed.

As a specific proposal, Tadano proposes a "multi-display system". In this system, the display could be expanded according to a multi-tasking type software such as MS-Windows. Tadano reports that a superior user interface should be prepared for multimedia equipment, and that interfaces which are in higher demand should be developed.

Standardization of Source Materials Is Key to Cost Reduction

Along with the development of applications, a reduction in cost is key to the proliferation of LCD panels in the future. Authorities from the exhibiting companies were questioned regarding this point.

Some cost reduction measures expressed by all of the LCD panel manufacturers were efficient implementation of mass production systems, simplification of fabrication processes, and lower material costs. With regard to decreasing the number of fabrication processes required, Fujitsu and Sanyo are trying to decrease the

number of masks which are used. Other companies also seem to be taking the same approach.

With regard to requests of panel client companies, Toshiba proposes a relaxation of specification standards. That alone would reportedly make a difference in the yield. For personal computer applications, the specifications required by all of the client companies are basically the same, and this makes it easy to implement mass production systems. However, specifications for television applications are different, making production more adapted to numerous models and small quantities rather than mass production. NEC plans to develop its own materials manufacturing group, and thereby reduce cost. However, at present, it is taking all of the company's effort to achieve a reduction of 5 to 10%.

Inasmuch as the cost of source materials accounts for a large part of the overall cost of the panel, all of the companies view this as important. Some of the materials involved are the glass substrate, color filter, backlight, and driver IC.

First to be discussed will be the glass substrate. NEC Glass had an exhibit at the Semicon/FPD Yokohama '94 (held in conjunction with EDEX '94). NEC pointed out that the key to reducing cost was in standardizing the size and specifications of the substrate. Unification of the substrate size is progressing toward 360 x 465mm, but the specifications required by various manufacturers are still different, such as the number of panels produced per substrate and the shape of corner cuts. For this reason, production is shifting toward numerous varieties and small quantities, thereby preventing a drop in cost. However, standardization of glass substrates will likely progress with efforts proposed by SEMI.

With regard to color filters, many panel manufacturing companies are lowering costs by producing the filters internally. Kyocera is currently producing 100% of its filters internally, and does not plan to change this approach in the future. It also plans to sell the filters externally. Fujitsu plans to move its color filter production from the test operation at Susaka to its Yonago plant. After mass production starts up, 100% of the filters will be supplied internally. Fujitsu may also sell the filters externally if panel production expands.

Sanyo has several different groups involved in efforts to produce the color filters internally. At present, filters are being produced at Tottori Sanyo. Sanyo produces 100% of the color filters for STN-LCD applications internally. However, at present, all efforts are involved in production for STN-LCD panels, with none being produced for TFT-LCDs. As of April 1994, production was 40,000 filters per month, when calculated for the 9.4" size. This amount will be increased to 100,000 in the autumn of 1994. Sanyo also began selling the filters externally in April, and plans call for 100% production of color filters in the future within the Sanyo group.

Toshiba Raitek displayed backlights at the exhibit. The company's approach to cost reduction is to consider the balance between functionality and cost, to use as many common components as possible, and also to reduce the number of components required. Toshiba is also reexamining the materials used in backlights in terms of cost effectiveness.

Japan Texas Instruments had an exhibit of driver ICs. Cost reduction measures being considered by the company are to change the current 18V drive to a 5V drive, and to incorporate the driver ICs into one chip. In doing so, the chip package will have a high pin count, but the cost of the package will not vary by much even in the pin count is changed from 120 (current) to 240. This will result in lower assembly cost and also a drop in the unit price of the driver IC. Standardization of driver IC specifications is also viewed to be important.

In terms of source materials used, standardization again seems to be the most emphasized in achieving cost reduction. However, the panel manufacturing companies tend to seek materials which meet their own specifications in order to differentiate their products. Even at Electronic Display Forum '94, when a manufacturing company stated that unification of substrate size was important to reducing the cost of color filters, a client asked what the specification tolerance would be if orders were combined. This being the case, it seems that standardization of source materials is only now beginning.

Table 1. Major Products Exhibited

Name of Company	Product Name	Display System	Display Colors	Pixels	Pixel Pitch (mm)	Pixel Arrangement	Screen Dimensions (inches)	Brightness (cd/m)	Contrast	Response Time (ms)
NEC	NL6448 AC30-09	TFT	Full color	640 x 480	0.30 x 0.30	RGB	9.4	120	110	40
	NL6448 AC30-10	TFT	4096	640 x 480	0.30 x 0.30	RGB	9.4	90	110	40
Kyocera	KCS6448 ASTT	STN	8	640 x 480	0.10 x 0.30	RGB	9.4	70	23	300
Sanyo Electric	AL0602	TFT	Full color	720 x 236	0.166 x 0.386	Triangular	5.9	205	-	-
Sharp	Reflective-type TFT-LCD	TFT	4-color Multi-color	240 x 320 x 2 (CR)	0.15 x 0.30	Delta	5	-	-	-
	-	STN	8	640 x 480	0.30 x 0.30	RGB	9.4	80	40	300
Seiko Epson	F07KM200	TFT	Full color	600 x 230	0.023 x 0.044	Delta	0.7	-	200	-
	LB4F	MIM	262,200	442 x 238	0.173 x 0.273	Diagonal mosaic	4.0	80	-	-
Sony	LMD-1040XC	TFT	16,700,000	640 x 480	0.30 x 0.30	RGB	10.4	100	100	-
Toshiba	LTM09 C020	TFT	512	640 x 480	0.30 x 0.3	Stripe	9.5	70	10	100
	TLX-8102S-C3X	F-STN	512	640 x 480	0.30 x 0.30	Striped	9.5	60	18	300
Tottori Sanyo Electric	LM-CC53-22NTK	F-STN	256	640 x 480	0.330 x 0.31	RGB	10.3	70	20	30
	LM-CD53-22NTK	F-STN	256	640 x 480	0.30 x 0.3	RGB	9.4	90	20	300
Hitachi Ltd.	TX24D55 VC1CAC	TFT	4096	640 x 480	0.30 x 0.30	RGB	9.4	70	100	50
	LMG9300 XVCC	STN	512	640 x 480	0.330 x 0.318	RGB	10.3	70	26	270
Fujitsu	-	TFT	16,700,000	640 x 480	0.33 x 0.33	RGB	10.4	200	50	-
Hoshiden	HLD0914	TFT	Full color	960 x 463	0.191 x 0.297	Delta	9	150	100	50

Note: Long dashes indicate "no comment".

and their Specifications

Weight of Panel (g)	Power Consumption (W)	Viewing Angle	Applications	Shipping Schedule and Future LCD Developments
-	10	upper/lower 30°, left/right 45°	Notebook PCs, multimedia applications	Δ Samples will be shipped in June or July 1994; mass production will begin Fall 1994 or later Δ Color TFT only. Mid-level notebook PC applications will be covered by former 4096 color type. A new analog full-color panel will be added for new consumer applications.
-	5	upper/lower 25°, left/right 45°		
-	3	-	Notebook PCs, office automation equipment	Δ Samples now being shipped. Mass production will begin soon. Δ STN type only. Panels for SVGA are now being developed.
-	10	upper/lower -20° to +10°, left/right 45°	VTR/TV combos, TV	Δ Now being developed Δ Mass production system ready for 6" and smaller color TFT-LCD
-	0.5	100° both upper/lower and left/right	Portable type data terminals	Δ Shipping of samples and mass production are undetermined. Δ Color TFT-LCD will be for high-end notebook PCs, office equipment, and automobile TVs. Color STn-LCD will be fore mid-level notebook PCs and video games.
490	3.4	upper 10°, lower 5°, left/right +/-20°	Notebook PCs	
3	0.1	Directly in front	Projectors, viewfinders	Δ F07KM200 currently mass produced at 100,000 pieces/month. LB4F will enter into mass production Fall 1994. Δ 2.5 - 4.5" Super MIM-LCD will be used in portable TVs and automobile TVs. Poly-Si TFT-LCD will be for viewfinders.
-	-	upper/lower -10°, +20° left/right +/-50° or more	Automobile TVs, TV telephones	
2600	40	upper/lower -15°, +10° left/right 45°	PCs, TV	Δ Samples are now being shipped. Although mass production schedule is not set, the production line is ready. Δ Poly-Si TFT-LCD will be produced for viewfinders.
49	3.6	-	Notebook PCs	Δ Timing of sample shipment and mass production is not set. Δ LCD will be supplied to meet customer needs according to market without focus on specific applications.
510	3	-		
540	-	upper/lower 35°, left/right 60°	Notebook PCs	Δ Each type is now being mass produced at 10,000 to 20,000 pieces/month. Δ Focus is on color STN-LCD for notebook PCs.
435	-	upper/lower 35°, left/right 60°		
-	3.6	upper 15°, lower 40°, left/right 35°	Notebook PCs	Δ 9.4" TFT currently being mass produced at several thousand per month. Samples of 10.3" STN will be shipped in August or September 1994. Δ Focus is on notebook PC applications. TFT-LCD will be used for high-end products and STN-LCD will be used for mid and lower level products.
560	3.4	25° both upper/lower and left/right		
1000	19	upper/lower +/-60° or more, left/right +/-70° or more	Desktop PCs	Δ Timing of sample shipment and mass production not yet established. Δ Applications will center on multimedia equipment.
360	-	upper/lower 90°, left/right +/-50°	TV	Δ 260,000 color display type (HLD0918) is scheduled to be shipped before the end of 1994.

Trends and Outlook for the Semiconductor Industry in the Latter Half of the 1990s

94FE0739A Tokyo DENSHI in Japanese May 94 pp 8-15

[Text of speech by Norio Sobashima, Director of Marketing, Semiconductor Operations Division, Hitachi Ltd. (see endnote)]

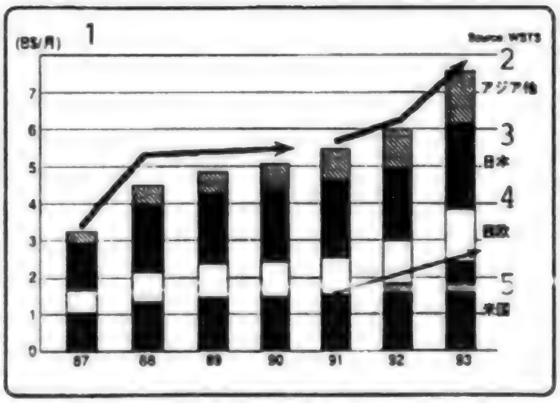
[Text]

Will Asian Countries Outpace Japan in the Semiconductor Industry?

Today I would like to talk about what we think will occur in the future based on past statistics of the semiconductor industry.

First of all, Figure 1 shows changes in the world semiconductor market region by region. From 1991 to 1993 the Japanese market appears to have expanded quite a bit when converted to dollars, but if we take into account the appreciation of the yen, 1991 and 1992 actually recorded negative growth, and although 1993 finally rebounded to a positive growth of about 10%, the slump in the market has continued.

Fig. 1 World Semiconductor Market (by region)



Key: 1. (B$/month); 2. Other Asian countries; 3. Japan; 4. Western Europe; 5. U.S.

After its previous peak in 1988, the world demand for semiconductors continued to show slow growth from 1989 to 1991. The reason for such slow growth was a slump in the U.S. market and a decline in the Japanese market's capacity for growth. This period corresponds to the peaking and subsequent bursting of the bubble economy in Japan.

At that time, the prospects for the world's semiconductor makers were rather dreary, and Japanese manufacturers were not aggressive with their investments. Since 1991 U.S. makers have made strong advances, and their momentum is expected to carry them even higher in 1994.

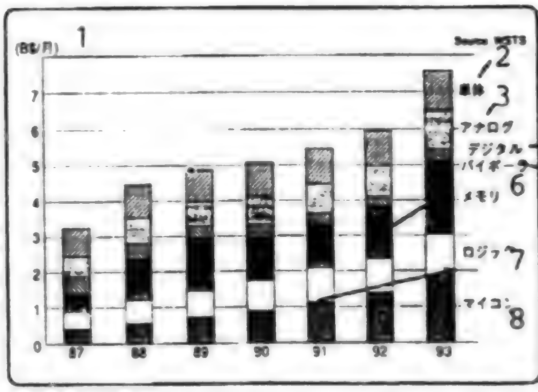
If we compare the makeup of the world's semiconductor market by region, from 1988 to 1991 Japan accounted for roughly 40% of the world market, but the position of the U.S. rebounded in 1992-1993, and in 1993 it appears the U.S. will regain its position as the world's largest market after an 8-year absence. Over that period Japan's position in the world market plummeted because of the bursting of the bubble economy, a slump in the sales of consumer electronics and office automation equipment, and shift to overseas production to offset the appreciation of the yen. Japan is now in second place behind the U.S.

On the other hand, the market share of other countries in Asia has shown outstanding growth and is currently at 19%. This market has now pulled even with the European market, and is certain to pass it this year.

If this trend continues, this market may surpass Japan by the year 2000. If Japan does nothing, it is almost certain to happen.

Next, if we look at the world market product by product, microcomputers have shown outstanding growth (Figure 2).

Fig. 2 World Semiconductor Market (by product type)



Key: 1. (B$/month); 2. Elemental semiconductors; 3. Analog; 4. Digital; 5. Bipolar; 6. Memory; 7. Logic; 8. Microcomputers.

Logic devices (ASICs, custom logic devices, gate arrays, etc.) have grown right along with microcomputers because they are used in microcomputer peripherals.

MOS memory, on the other hand, peaked in 1989 and showed almost no growth at all in 1990-1991 because the prices of the 1M DRAM began to fall, and the generational changeover to the 4M DRAM was delayed. In 1992-1993 MOS memory began to show clear growth once more, and Japanese semiconductor makers breathed a collective sigh of relief as the demand for memory devices shot up.

The reason for the sharp increase in the demand for memory devices lies in the technological revolution brought about by the microcomputer. Because products with extremely sophisticated technology appeared, the amount of memory needed per machine jumped considerably. Therefore, memory sales are expected to increase again in 1994 thanks to both the increase in the number of PCs produced and the increase in the amount of memory used per machine. When the 16M appears there may be some fluctuation during the

4M-16M borderline period, but basically the trend toward requiring lots of memory should continue through the end of this year. On the other hand, digital bipolar devices showed the greatest drop.

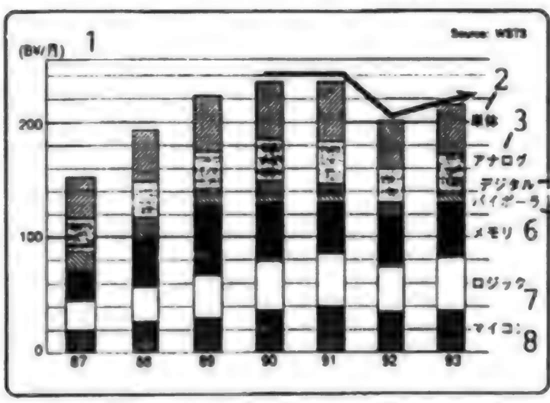
These products have finally been absorbed by microcomputers. Probably, their only remaining use will be cases in which TTLs must be used because the system designers do not have enough time to design the LSIs. Elemental semiconductors are following the same trend, and in the future their share will be winnowed down to only a small percentage of the market.

This reflects the natural flow of technological progress, and the three mainstays of MOS-LSIs, microcomputers, logic, and memory have already reached a 68% share, and before long MOS-LSIs will reach 75%-85%. In the 21st Century, the word semiconductor will mean MOS-LSI, and only the few transistors and TTLs whose use is unavoidable will remain.

Japanese Market Goes Against World Trend

Thus, since 1990 the world market overall has recovered considerably, but a conspicuously different trend has appeared in Japan. In 1987-1989 while the world market was sluggish, the Japanese market expanded, relatively speaking (Figure 3).

Fig. 3. Japanese Semiconductor Market (by product type)



Key: 1. (B$/month); 2. Elemental semiconductors; 3. Analog; 4. Digital; 5. Bipolar; 6. Memory; 7. Logic; 8. Microcomputers.

However, beginning in 1990 the bubble burst, and Japan's economy went into a tailspin. Zero growth in 1991 was quite a shock, and although 1992 had been expected to be a peak year in the silicon cycle, the market recorded a horrid -12% growth when converted to yen. This was negative growth in the midst of a strong recovery worldwide, and if we make an analogy with golf, it is like taking a triple bogey when your competitors make birdie.

This was a major shock to Japan's semiconductor industry, and it meant that some kind of major transition is underway in the Japanese market. Right now the industry is doing lot of analysis to find out what is going on. However, domestic demand includes not only shipments by Japanese manufacturers, but imports as well. More specifically, microcomputers are growing in the world market but not in Japan, and memory is not growing much either. In other words, the technological revolution underway in the U.S. with its focus on downsizing has not yet occurred in Japan.

PCs are being imported from overseas, and Japanese PC makers are putting out inexpensive machines, so the marketplace has become quite exciting, but in terms of semiconductor demand a major effect such as what we saw in the U.S. has yet to become evident.

On the other hand, the market for consumer electronics and automobiles is dismal, and no prospects of recovery are in sight.

Overall, the domestic semiconductor market can be expected to grow 5%-10% in 1994, which is a very bitter pill to swallow.

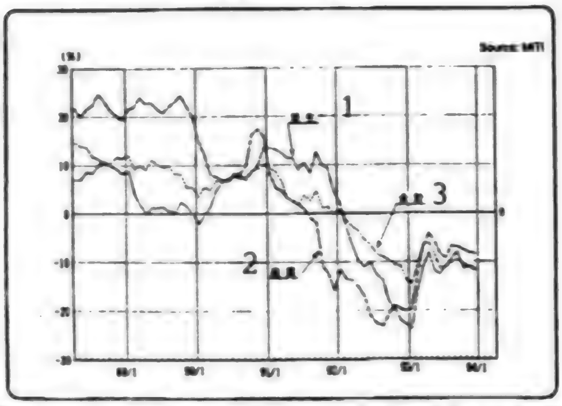
When we look at world trends in technology, the U.S.-European type structure, which promotes the development of new data and telecommunications equipment like personal computers that incorporate peripheral LSIs, is still almost non-existent in Japan, and that is the major weakness of the Japanese market. In the past, the national character of the Japanese people and Japan's social structure, both of which eschew rapid change, have provided a kind of sanctuary for us, but now this has become an obstacle. A rapid technological revolution has been underway worldwide for the past 2 or 3 years, and in the midst of all this change only Japan has remained the same. Therefore, we must conclude that the current recession is not merely a problem of economic circulation, but a problem rooted in the nation of Japan as a whole. More specifically, almost everything—Japan's industrial structure, culture, lifestyle and so on—is being challenged, and the data clearly shows that we must ask ourselves if it is not time to change.

Moreover, when we look at the production of electronics equipment, we find that after recording its first negative growth in February 1992 production has remained below zero and has yet to move toward positive growth (Figure 4).

Production of electronics equipment for industry fell first, recording negative growth from the middle of 1991. It appears that businesses cut back on their facility and information processing equipment when the bubble burst, and that led to a drop in sales of electronics equipment for industry. Production of personal electronics equipment fell after a short delay because there was a slight time lag before the drop in corporate profits affected employees in the form of cuts in pay and bonuses.

However, the semiconductor industry enjoyed a relatively good period at the end of last year. What I mean is

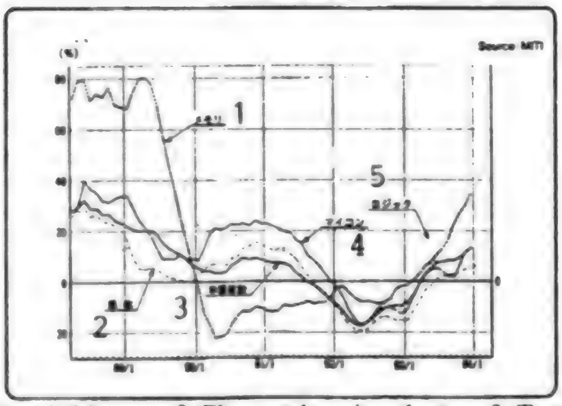
Fig. 4. Production of Electronics Equipment in Japan (Average changes over three month periods, comparison with previous year)



Key: 1. Consumer products; 2. Industrial products; 3. Total.

that since the spring of 1993, the demand for semiconductors has been expanding (Figure 5). In other words, even though the production of electronics equipment is still shrinking, the domestic demand for semiconductors has returned to the plus side of the ledger. Logic and memory devices in particular have recorded rather strong growth.

Fig. 5. Semiconductor Market in Japan (Average changes over three month periods, comparison with previous year)



Key: 1. Memory; 2. Elemental semiconductors; 3. Total semiconductors; 4. Microcomputers; 5. Logic.

I am not exactly sure how to interpret all this, but one explanation could be that more semiconductors are being used in electronics equipment.

Another reason could be the appearance of new equipment that is not reflected in the statistics on equipment production. One example would be software used for electronic games. These games use EP-ROM and mask ROM.

In addition, the semiconductors may not actually be incorporated into domestically produced equipment; that is, they may follow a circuitous route and be exported indirectly. For example, they may show up in Asia and the U.S. as memory boards and modules.

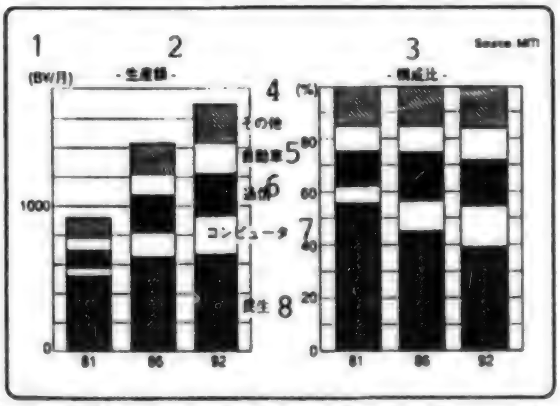
Furthermore, even though the production of personal electronics equipment and data equipment has been shifted overseas, there are customers who continue to buy their semiconductors in Japan.

In any event, if we try to predict semiconductor demand from the trends in electronics equipment using the methods we have used in the past, our results will be way off the mark. This makes our job more difficult, but as far as the semiconductor industry is concerned, we should be thankful that semiconductor demand is increasing regardless of the slump in electronics equipment production.

Industrial Equipment Cannot Compensate for Slump in Consumer Electronics

Next, if we look at electronics equipment production over a slightly longer period of time, we see that it grew strongly from 1981 through 1986, but growth fell off between 1986 and 1992 (Figure 6).

Fig. 6. Production of Electronics Equipment in Japan



Key: 1. (B$/month); 2. Production Total; 3. Composition; 4. Others; 5. Automobiles; 6. Communications; 7. Computers; 8. Consumer products.

Clearly, electronics equipment production in Japan no longer enjoys high growth rates, and one reason is a decline in our competitive strength. Another reason is the fact that domestic production has dropped, especially because companies have been unable to continue production at home due to appreciation of the yen and have shifted that production overseas.

In the past, personal electronics equipment accounted for nearly 60% of electronics equipment production in Japan, but in 1992 it fell to 40%. If this trend continues,

it will drop to 20%-25% by the year 2000, and the peoples in other Asian countries will gradually take over in this area.

Naturally, there are high-profile commercial products among personal electronics equipment with very sophisticated technology such as MD-DCC or the highly-touted HDTV, but they will not have the power to hold back the downward spiral. If we look at the major cycles in consumer electronics, we see color TV in the 1970s, VCRs in the 1980s, and HDTV predicted for the 1990s, but HDTV has yet to reach maturity. There is no product today in consumer electronics to rival the products that were big hits in the previous two cycles. HDTV is unlikely to become a hit product for another five years or so.

Therefore, the products to compensate for the drop in consumer electronics are items such as office automation equipment, computers, and communications equipment rather than personal electronics products. Hopes are especially high for office automation equipment, but unfortunately this area will be hard pressed to compensate for the drop in personal electronics products, and it still does not have the strength to turn things around.

Actually, computers ought to be doing better than they have been, but since mainframes have run into trouble since the bubble burst, the technological revolution toward downsizing is not moving ahead everywhere in Japan.

Communications equipment has been heavily regulated in the past, but finally last year the gradual relaxation of regulations began, and this field offers something to look forward to in the future. However, I think that it will take five to ten years before these changes appear in concrete form. In any event, cellular phones can now be purchased rather than leased, competition among networks is beginning, and phone rates will become cheaper. All of these changes will take time, however.

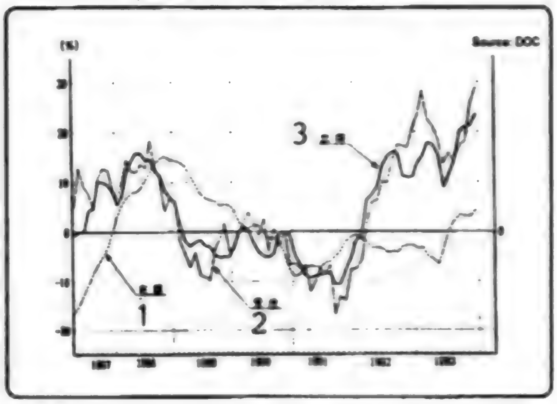
The U.S. 'Laughs Best' and a Miraculous Coincidence

If we look at what is going on with the U.S., the expression "He who laughs last, laughs best" fits nicely. The U.S. was struggling badly while Japan was floating along on its economic bubble. The Big 3 automakers were in the red and laying off workers, and the American semiconductor association (SIA) was howling about dumping and lack of access to the Japanese market. The computer and telecommunications equipment industries were in bad shape. Then in 1992, the same year that Japan first recorded negative growth, the Americans were suddenly back in the black (Figure 7)

This was quite a coincidence, and I do not think we can explain things away merely by saying that the Japanese market declined when the American market expanded. Even more surprising, these events occurred in the same month, February. In the future this event will probably be considered just a miraculous coincidence.

Regardless, there were major changes worldwide such as the breakup of the Soviet Union. The dollar tends to show its strength in times of crisis, and when something in the world occurs that causes Japan's fortunes to fall and America's to rise, we feel the basic strength underlying the U.S. economy.

Fig. 7. Computer and Office Equipment Production in the U.S. (Average changes over three month periods, comparison with previous year)

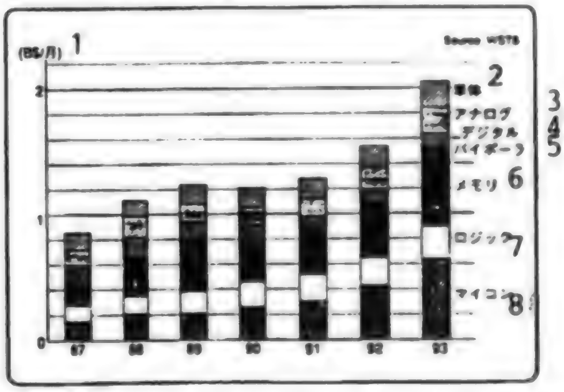


Key: 1. Stock; 2. Orders received; 3. Shipments.

The U.S. Commerce Department has announced that the American economy is on the way to a strong recovery this year, and in 1993 computers/office automation equipment sales will increase 10-15% over the previous year. Because this momentum will continue in 1994, the U.S. economy should be healthy through the end of this year, and sales of memory devices and microcomputers that will be used in the U.S. should also be healthy.

In short, in 1989 the U.S. semiconductor market went into a slump, recorded negative growth in 1990, went sideways in 1991, and then in 1992 and 1993 recorded sharp growth (Figure 8).

Fig. 8. U.S. Semiconductor Market



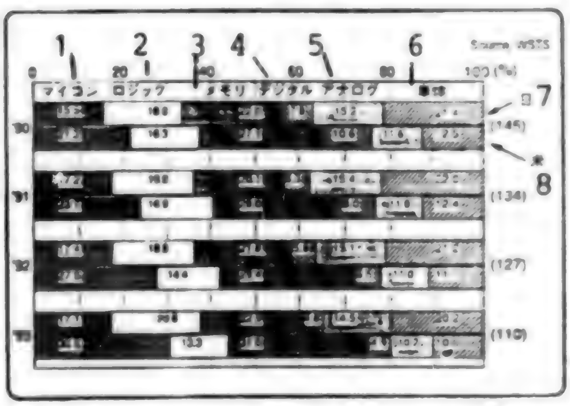
Key: 1. (B$/month); 2. Elemental semiconductors; 3. Analog; 4. Digital; 5. Bipolar; 6. Memory; 7. Logic; 8. Microcomputers.

This growth was initially triggered by the increase in microcomputer sales, and then in 1992 sales of memory devices also began to increase. Thus, the U.S. market has made a strong recovery. More specifically, what was especially outstanding was the prolific growth of the three MOS mainstays, and this is definitely the kind of pattern we see at the leading edge of a technological revolution.

What is really going on in the U.S.? In 1992 Compaq suddenly cut its computer prices in half, other personal computer makers followed suit, and this resulted in horrendous competition. It appeared for a while that some companies might go under, but in the end that did not happen. The leading manufacturers increased their shares of the market, and after a short time in the red, profits returned to the positive side of the ledger.

If we look at the composition of the U.S. market and compare American and Japanese products (Figure 9), we find that the U.S. has a larger percentage in the three MOS mainstays, and it is likely to maintain that position for some time. In 1994 the percentage will probably be about 80%. Conversely, bipolar digital devices, elemental semiconductors and analog devices have all slowly declined. In other words, because analog processing can be performed using MOS technology, analog/digital mixed LSIs are now being made in MOS form.

Fig. 9. Comparison of Semiconductor Market Composition in U.S. and Japan

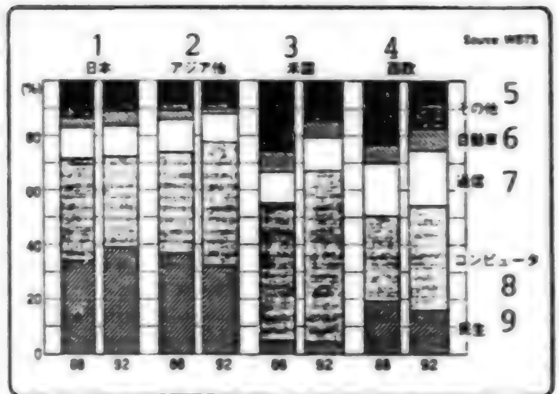


Key: 1. Microcomputers; 2. Logic; 3. Memory; 4. Digital; 5. Analog; 6. Elemental semiconductors; 7. Japan; 8. U.S.

The composition of the Japanese market, on the other hand, has barely changed at all. The percentage of the three MOS mainstays has at long last reached the 60% range. This level is lower than what the U.S. had in 1990. From the standpoint of technological progress, it appears that Japan cannot catch up to the U.S. and that we are slowly falling farther behind.

Now let us compare differences throughout the world in 1988 and 1992 by fields of semiconductor use (Figure 10).

Fig. 10. Semiconductor Market by Fields of Use



Key: 1. Japan; 2. Other Asian countries; 3. U.S.; 4. Western Europe; 5. Other; 6. Automobiles; 7. Communications; 8. Computers; 9. Consumer products

Japan is very similar to other Asian countries, with the demand for semiconductors for consumer products running around 40% of the total. On the other hand, in the U.S. only a small amount of semiconductor demand is for consumer products; it is almost all for computers. Europe falls between the U.S. and Japan, being somewhat closer to the U.S.

Among these four regions, Japan is unique in two points. One is that the percentage of semiconductor demand for computers, which should be growing the most, is declining. Even though the production of computer equipment is increasing, the demand for semiconductors for computer equipment is not increasing. Although the production of consumer products is dropping, the demand for semiconductors for consumer products is increasing. This phenomenon is observed only in Japan. Probably, the consumer products field is having a tough time and aggressively pursuing the technological revolution, so more semiconductors are being used in consumer products.

In fact, memory devices are now being used in many consumer products, and in many cases dedicated logic and ASIC devices are also being used. Thanks to these efforts by consumer electronics makers, the percentage of semiconductors used in consumer products has increased despite the drop in consumer product production.

On the other hand, the technological revolution has not made many inroads into semiconductors for computers, and this leaves an even stronger impression that Japan is moving in the opposite direction from the rest of the world all by herself.

However, when we refer to the computer field here, we also must include office equipment such as printers, fax machines, copiers and so on. The situation in Japan is somewhat different from other regions because Japan produces a lot of office equipment. What I want to point out here is the conspicuous difference in the amount of semiconductors used in microcomputers.

The 21st century will revolve around the LSI brains of microcomputers, and people who get involved with them early on and incorporate them into their equipment will rule the future. Japan has not made much progress in this regard; bipolar digital and analog devices and elemental semiconductors still have deep roots here.

Three Major Issues for Japan's Post-Bubble Economy

As you can see, Japan's economy is now facing a very tough situation, and the semiconductor industry has some problems of its own. I would like to point out three of these.

The first is the drop in stock and real estate prices with the bursting of the economic bubble. First of all, as a result, personal consumer items such as consumer products and automobiles were affected. In addition, the rapid drop in stock values held down corporate investments. During the bubble economy, Japanese companies issued new stock and convertible bonds left and right to gather up cash at very low interest rates. However, the assumption that stock prices would rise is no longer valid. If a company issues convertible bonds now, no one will buy them, and even if they sell, redemption of these corporate bonds is inevitable because they will not be converted into stock. I estimate that overall the semiconductor industry gathered in about one trillion yen. If that is the case, in the future semiconductor companies will have to borrow money from the banks, but now the banking business is busy coping with bad bonds and restructuring, so that will also be a bad situation.

The second problem is the appreciation of the yen. First, companies cannot make a profit on exports, but they also cannot make investments. Because they cannot make investments, this creates a vicious cycle that blunts Japanese industrial activity even more.

Moreover, restructuring has begun. Under the banner of streamlining, which includes changes in hiring practices, and rearrangement of personnel and affiliated companies, companies are cutting out jobs and personnel. This process occurred in the U.S. five years ago. Japanese companies that did nothing, considering events in the U.S. merely a "fire on the other side of the river," are now undergoing the same experience.

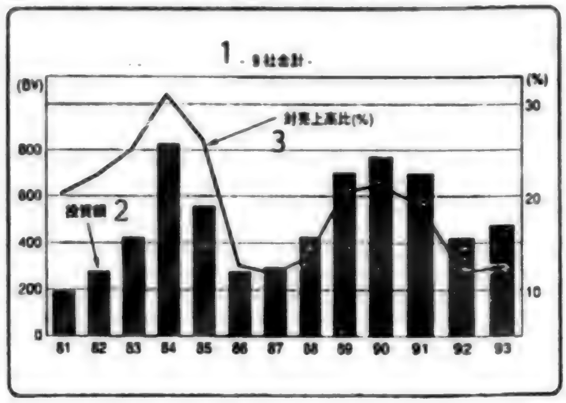
The third problem is the disarray in domestic and economic policies brought about by the political realignments forged from the scandals in the construction industry and their repercussions.

Thus, the harsh aftereffects of the collapse of the bubble economy remain with us today.

Investments of Japanese Semiconductor Companies that are Strapped for Capital

When we look at investments by Japanese semiconductor makers (Figure 11), corporate profits move together with the economic cycle. In 1984 the cash total surpassed 800 billion yen, and that was the past peak for cash investments. The next peak was in 1990, and in 1994 investments will probably be about 700 billion yen.

Fig. 11 Investments of Japanese Semiconductor Makers

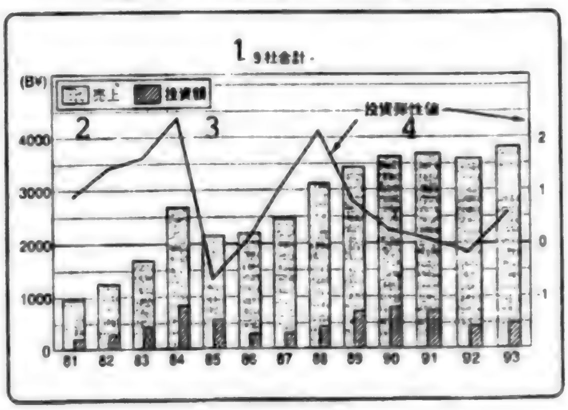


Key: 1. Totals from 9 companies; 2. Investments; 3. Comparison with sales volume

One characteristic is that companies are gradually moving away from large investments. The main reason is the discontinuity in cash flow, and at least for the time being, Japanese semiconductor makers will be struggling with the problem of how to manipulate their capital.

One other indicator is the investment rebound value (Figure 12).

Fig. 12 Investment Rebound Value



Key: 1. Totals from 9 companies; 2. Sales; 3. Investments; 4. Investment Rebound Value.

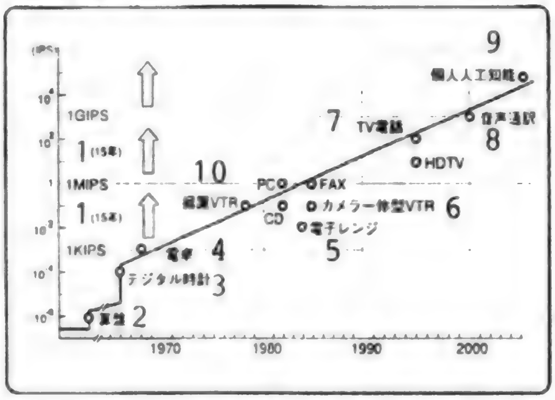
The investment rebound value shows some very dynamic changes. It is said that a company struggles if its investment rebound value does not go above 1, but a rebound value higher than 1 is becoming a real rarity.

In any event, as far as long-term trends are concerned, I get the impression that the pockets of Japanese corporations are not as deep as they were before, and they are losing their underlying strength.

Toward an Age of Networks Rather Than Data Processing

When we look at the history of technological development, after World War II the U.S. created the ENIAC computer, which was a collection of vacuum tubes, and ever since the majority of innovations in electronics technology have dealt with data processing (Figure 13).

Fig. 13. Development of Data Processing



Key: 1. (15 years); 2. Abacus; 3. Digital watches; 4. Electronic calculators; 5. Microwave ovens; 6. Camera-VCR unit; 7. TV telephone; 8. Audio interpreter; 9. Individual artificial intelligence; 10. Stand-alone VCR.

For example, digital watches and calculators of the 1970s could process about 1,000 commands per second. From a historical perspective, that means we have increased our data processing capability 1,000 times in 15 years.

This is an excellent record in itself, but now a problem has emerged. We have increased the speed of data processing, but have been unable to make full use of it. For example, this is similar to the fact that HDTV has not become widespread. The reason is because people do not understand why HDTV is so much better than conventional TV. This is partly due to a lack of information, but the high prices of HDTV receivers, the programming, and many other concerns have kept HDTV from widespread acceptance.

In other words, we have reached a time for making some small adjustments in the technological balance, and the most important point will be integrating network technology.

Just as human beings cannot live an isolated existence, even the most marvelous electronic device is not very helpful for one person alone. There will be little progress unless it is used to communicate with someone else.

Semiconductors and electronics equipment have been concerned only with data processing technology for the past 30 years, and I am beginning to believe that they will not go on to a higher level unless networks become more convenient and less expensive.

First was the arrival of personal computers and workstations, and next will come the age of mobile, portable computers exemplified by mobile communications and PDA. Therefore, in the future Japan will have to set up a network infrastructure for these.

At present digital networks called ISDNs have become rather common, and it is expected that there will be a digital network linking the whole nation of Japan by 1997 or 1998.

When that happens, because the switchers are digital, as terminals become available it will be possible to link personal computer signals, fax signals, and audio-visual signals, which are usually lumped together under the banner of multimedia, on the same circuits.

Thereafter will come the age of the super network that will carry a large volume of multimedia signals at high speeds, and it will probably utilize optical fibers. If optical fibers are used with digital switchers, the network can encode and carry the current microwave concentric cable signals such as TV images and photographs. It will become a fully integrated network, so personal, portable information devices can be hooked up with the same kind of feeling we have now about plugging a cord into an electrical outlet.

However, this dreamlike age will not arrive until about 2010, so it is still far away in the future.

Expectations for Asia as a Potential Market

How much of a gap is there between the U.S. and Japan concerning these 21st century devices? If we express it in numbers, the number of personal computers per 100 workers is 42 in the U.S., but only 9.9 in Japan. The number of cellular phones per 100 people is 4.4 in the U.S., and 1.4 in Japan. Sixty of every 100 people in the U.S. subscribe to CATV, but in Japan only 2.7% of the people have cable.

In the U.S. 1.1 million personal computers are linked to the INTERNET network, but in Japan only 39,000 can now go online.

As you can see, the gap in technological progress is quite wide between the U.S. and Japan.

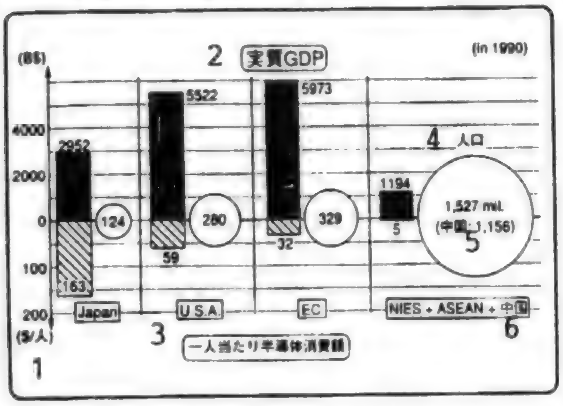
I have spoken rather pessimistically so far, but I would like to end on a more optimistic note.

This is data from 1990, and it divides the world into four regions (Figure 14).

When we look at this graph, in terms of numbers Japan consumes many more semiconductors per person than the U.S. or Europe. These figures are encouraging, but the breakdown makes me very uneasy when I think about the future events I just mentioned.

There is one region, however, that does not compare. This is NIES, ASEAN and China, with a combined

Fig. 14 Comparison of Market Potential



Key: 1. ($/person); 2. Actual GDP; 3. Total semiconductors consumed per capita; 4. Population; 5. (China: 1,156); 6. NIES+ASEAN+China

population of 1.5-1.6 billion people. The region's economic activity is still about one-third that of Japan, and only a few semiconductors are used per person. But what will this region be like in 2000? Of course, some reservations remain, but I believe this region represents a huge opportunity.

In Japan we tend to associate the concept of "overseas" with the U.S. and Europe, but these are mature regions similar to Japan, so we cannot expect major opportunities there in the future. Therefore, I believe that Japan should develop the great potential market of Asia. This region also has the advantage of being in the same part of the world geographically.

More than half of what I have discussed has not been pleasant to listen to, but this huge, potential market of Asia is sitting right beside us. This is a fine region for Japan to look to with high hopes for the future, and I think we must start working hard now to develop the Asian market.

Note: This article is from a speech recorded at the New Year's Joint Conference of the Semiconductor Industry Parts Steering Committee, Resources Committee, and Material Makers Forum held on 27 January 1994.

Stable Fabrication of Fine-Pattern Gate Structures as Small as 0.1 Micron Expected Soon

94FE0654 Tokyo NIKKEI MICRODEVICES in Japanese May 94 pp 76-77

[Text]**The NEC Microelectronics Laboratory has developed a technique which doubles the selectivity of sublayer oxide film during etching of polycrystal silicon to a value of 50 or greater. The new technique provides decreased static electricity and improved anisotropy. Increasing the selectivity makes it possible to maintain a throughput about the same as conventional techniques. The new technique can be used to improve 0.5μm rule processes, and can also be used at the 0.1μm level. Plasma is generated intermittently, since the ionic energy which governs the etching of sublayer oxide film is lowered without reducing the ionic density, which governs the etching of the polycrystal silicon.**

The selectivity and anisotropy of etching has been improved along with the achievement of smaller structural size. Selectivity needed to be improved because of the film thinness, and anisotropy needed to be improved due to the high aspect ratio of gate polycrystal silicon. To achieve this, LSI manufacturing companies have been promoting the development of a plasma source which can lower both the reactive ionic energy and the chamber pressure. Typical examples of this are magnetron RIE and ECR. With lower energy levels, selectivity can be improved, and with lower pressure levels, the collision of similar radicals, which deteriorates anisotropy, can be prevented.

Selectivity, Anisotropy, Electrostatic Characteristics Improved

NEC has improved the process using a method in which plasma is generated intermittently. This method is not related to the type of plasma source. (Refer to Samukawa, Proceedings of the 41st Conference of Applied Physics Society, No. 30 a-ZF-4, March 1994.) The selectivity can be coubled by generating the plasma at 10 microsecond intervals (see Figure 1). The problems associated with static electricity and anisotropy can also be improved without causing a lower throughput.

The reason that selectivity is improved is because a lower energy level is used wnile maintaining a constant ion density (see Figure 2). High energy ions which occur during the period that plasma is generated change to low energy during the period that the plasma generation is stopped.

The reason that the ionic density must be kept constant even for intermittent plasma is because the lifespan of the ion is 50 microseconds long. By shortening the time during which plasma is not generated to 10 microseconds or less, an ionic density which is about the same as for continuous plasma can be achieved for the periods when plasma is generated and also periods when it is not generated. When the ionic density is fixed, the etch rate of polycrystal silicon, which occurs chiefly by chemical reaction, does not change. In this way, polycrystal silicon can be etched at about the same rate used with continuous plasma generation.

The reason that ionic energy drops during the non-generating time is because the energy relaxation time is on the order of nanoseconds. Ions which have reached a low energy level cannot etch oxide films because oxide films are etched chiefly by physical reaction. As a result, oxide films are only etched when plasma is generated and ionic energy is high. Etching does not occur when plasma generation is suspended.

Selectivity Can be Improved Even More

A selectivity value of about 50 can be achieved using the new method, but NEC feels that this can be improved even further by lowering the duty factor. For example, plasma generation can be suspended for 10 microseconds or less, and the generation interval an also be shortened. A generation interval of several microseconds is sufficient. This is because etching of oxide film is thought to occur during plasma generation when high energy is present, and shortening this time interval will lower the etching rate. When a duty ratio of 50% was used during testing, the etch rate dropped 50% relative to continuous plasma.

Electrostatic charge was decreased by half relative to continuous plasma generation. This is because lowering the energy level while plasma generation is suspended reduces the rate variance of ions and electrons. (The rate variance causes static electricity.) The electrostatic charge was measured using an EEPROM. The EEPROM was placed into the chamber, plasma was generated, and the charge which accumulated at the floating gate of the EEPROM was measured at that time.

Anisotropy has also been improved, because the lower energy level results in less of a horizontal rate component on the wafer. The vertical component does not change, because it is determined by the substrate bias. As a result, the direction of ion movement is perpendicular to the wafer. Since the new fabrication method is not dependent on the plasma source, various types of high density plasma sources can be used, such as helicon and TCP. The new method can also be used to improve the performance of existing equipment—only the power source needs to be reconstructed. There is, however, a problem of plasma stability with 13.56MHz plasma when a plasma generating interval of 10 microseconds or less is used. This is because using an interval of 1 to 2 microseconds approaches ten times 0.07 microseconds, which corresponds to a frequency of 13.56MHz. Reconstructing the power source to enable intermittent plasma generation will be more expensive than the conventional power source used with continuous plasma generation. However, the cost will be less once the method becomes widely used.

Research Continues on Physical Properties

The reason why NEC has shifted research efforts from comparing plasma sources to methods of using plasma is because there are no longer major differences among plasma sources. The various plasma sources currently in use are being improved, and "plasma density and uniformity (which have been points of competition in the past) have reached sufficient levels for all types of plasma," according to S. Samukawa of NEC's Microelectronics Laboratory. This is why research efforts have been redirected toward methods of using the ionic energy, which is a physical property of the plasma.

NEC will continue to examine the physical properties of plasma, such as electron temperature distribution and ionization rate. To facilitate the achievement of ideal physical properties, the various types of plasma sources will be compared and examined again.

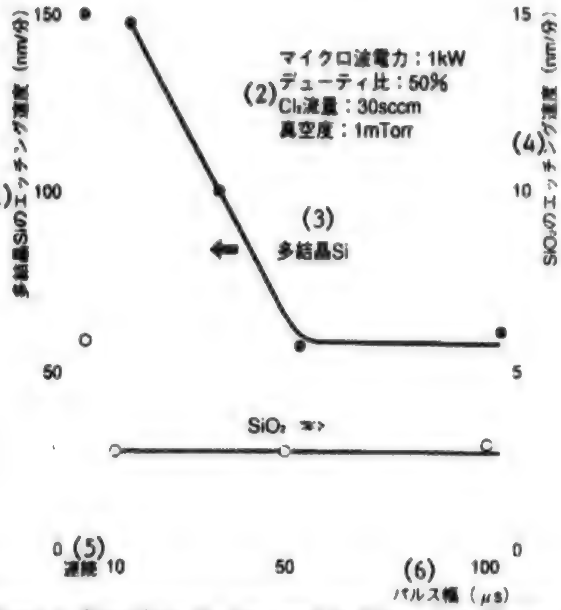
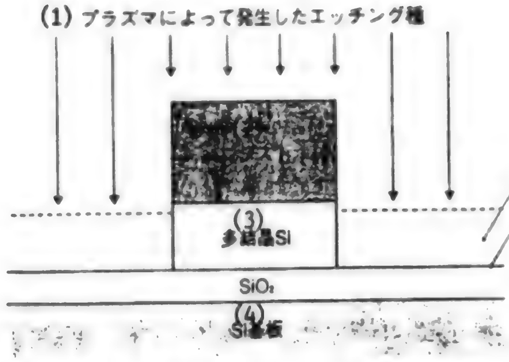


Figure 1. Selectivity Is Improved by Generating Plasma Intermittently Compared to the conventional method, in which plasma is generated continuously, selectivity can be doubled by using a time modulation method where plasma is generated intermittently at a pulse width of 10 microseconds and duty ratio of 50%. Throughput remains the same as conventional methods, because the etch rate of polycrystal silicon does not drop. Although ECR was used as the plasma source, NEC maintains that other plasma sources can also be used.

Key: 1. Etch Rate of Polycrystal Silicon (nm/min) 2. Microwave power: 1kW Duty· 50% Cl_2 flow: 30sccm Vacuum: 1m Torr; 3. Polycrystal Si; 4. Etch rate of SiO_2 (nm/min); 5. Continuous; 6. Pulse width (microseconds)



	(5) エッチング反応	(6) 関連するパラメータ	(7) タイム・モジュレーションを使うことによる関連パラメータの変化	(8) タイム・モジュレーションを使うことによるエッチング速度の変化
(9) 多結晶Si	(10) 主に化学反応	(11) プラズマ密度	(12) 一定*	(13) 一定*
SiO₂	主に物理反応 (14)	プラズマ・エネルギー (電子温度) (15)	低下 (16)	低下 (17)

Figure 2. Selectivity Is Improved by Using Reaction Differences Selectivity is improved because low energy ions etch only the polycrystal silicon, and not the oxide film. Since the etching of polycrystal silicon occurs chiefly by chemical reaction, it is dependent on density. The etching rate is fixed because the density does not change. Since the etching of oxide film occurs chiefly by physical reaction, it is dependent on the amount of ionic energy. The etch rate drops with a lower energy level. *Comparison between continuous and 10 microseconds pulse interval.

Key: 1. Etching caused by plasma; 2. Resist; 3. Polycrystal silicon; 4. Si; substrate; 5. Etch reaction; 6. Related parameters; 7. Changes in related parameters by using time modulation; 8. Changes in etch rate by using time modulation; 9. Polycrystal Si; 10. Chiefly chemical reaction; 11. Plasma density; 12. Fixed*; 13. Fixed*; 14. Chiefly physical reaction; 15. Plasma energy (electron temperature); 16. Lower; 17. Lower

Gene Therapy Research Association Plans Guideline for Diagnosis of Gene-Therapy Diseases

43070103E Tokyo JAPAN CHEMICAL WEEK in English 19 May 94 p 5

[Text] Gene Therapy Research Association has been started by researchers, private businesses and others so as to work out a guideline for diagnosis of diseases that require gene therapy as well as attempt to produce a consensus with regard to gene therapy.

Professor T. Mori of Kyoto University, one of the association's leaders, says: "We'll offer the newest information on clinical application of gene-research finding, try to obtain and deepen people's recognition and understanding of the roles of gene therapy in medical treatment, and offer opportunities for those concerned, including ordinary people, to discuss how gene screening should be carried out-a significant future theme".

The association plans to elaborate the diagnosis guideline for gene-therapy application within two to three years, and will have its first meeting in December to study the problems involved. It is led by two representative managers including Mori, 13 managers and six advisors. Annual membership fees are ¥5,000 for an individual member, and ¥100,000 for a corporate member; the number of members is expected to reach 2,000-3000. About 50 companies have already joined it.

It is believed that diagnosis for gene therapy involves problems with regard to human rights and personal secrets, which may, unless appropriately controlled, develop into grave social problems, Mori warns.

MITI Presents Target Areas of Chemistry Research

94FE0707A Tokyo KAGAKU KOGYO NIPPO in Japanese 25 May 94 p 1

[Text] The Ministry of International Trade and Industry (MITI), which had been studying its 1995 R&D policy for the chemical field, has established three major goals, namely, creation of a new industry, protection of environment, and ensuring safety and reliability. In selecting themes for the creation of a new industry, MITI has gone beyond the usual super carbon and other advanced materials by including new process and basic technologies shared by all fields, such as the next generation of reaction process, aimed at simplification of the process, and computerized chemistry. These technologies will contribute to improvement of the environmental protection and safety aspects of chemical substances. At the same time, MITI's 1995 policy will stress the expansion of the foundation of R&D, the so-called "technoinfrastructure." More specifically, the construction of a safety test database and safety information network most likely will be coming up as research topics.

Although the chemical industry owed its development to the industry's continuing efforts under strong R&D leadership, in recent years, large-scale research projects have not been producing results. Moreover, the long-term recession of recent years is forcing many chemical companies to restructure, and in the process R&D divisions were cut back severely. Emergence of global environmental problems and need for more stringent chemical substance safety measure also are casting shadows on chemical R&D.

Having decided that the creation of new materials is essential to revitalization of the chemical industry, MITI is now moving in the direction of new composite materials and new structural materials. It will select the super carbon, currently under development at the Agency of Industrial Science and Technology, as well as smart structural materials and super molecular materials as new material development themes following those of silicon group polymer, auto-response, and precision-polymerization macromolecular materials. At the same time, MITI will be undertaking the development of such a new process technology as the next generation of reaction process (the simplest chemistry) comparable to C_1 chemistry of the past years. Also pursued by MITI will be computer chemistry.

In the area of environmental protection, MITI will undertake the development of decomposition technology of freon and other substances considered hazardous to environment, as well as oilization and monomer reduction techniques to be used in plastic waste treatment.

MITI felt that the government's role in ensuring safety and reliability of chemical substances is to develop basic technologies applicable to all fields, and accordingly plans to pursue research in high-speed and high-sensitivity measurement test of environmentally hazardous chemical substances.

STA's NISTEF Announces Survey Report on Future S&T Activities in Japan, Germany

94FE0707B Tokyo KAGAKU KOGYO NIPPO in Japanese 26 May 94 p 1

[Text] STA's NISTEF (director: Fujio Sakauchi) announced on 25 May 1994, the issuance of a survey report dealing with the forecasting and comparison of future scientific activities in Japan and Germany. According to the report, periods covered by the forecast for total technological achievements of Japan and Germany are approximately the same, 2006.4 for Japan and 2006.1 for Germany. Those technological problems whose solutions will not be achieved prior to 2009 are in the three fields, viz., life science, energy, and elementary particle. German and Japanese predictions are in agreement on this. Conversely, technical problems which are shared by Japan and Germany and whose solutions are predicted prior to 2005 are in the fields of "ocean and earth," communications," and "city, construction, civil engineering." The comparative analysis clearly indicates the Japanese weakness in basic research and differences between Japanese and German approaches toward joint international development.

This survey was conducted to probe future science and technology recognized by both Japanese and German experts and problem areas likely to be encountered during the course of technical development. The report compares and analyzes the findings of technical forecasting surveys thus far conducted by Japan's STA and Germany's BMFT. The number of technical forecasting problems compared is 1,046. The period covered by the forecasting is 30 years beginning in 1991 and ending in 2020.

Importance of "Explication" Stage Increases

In examining the Japanese and German perceptions of international joint developments, it was found that both felt that international cooperation is essential to the fields of "life science," "environment," "health and medicine," and "space." When trends are looked at by stage showing technological phase, the "explication" stage was evaluated as the most important by both countries, indicating the importance of basic research.

When the attitude of both countries toward international cooperation was examined using the level of R&D as criteria, it was found that while Germany stressed international cooperation irrespective of the level of standard, Japanese attitude was that the higher the standard of its own problems, the less need was felt for international cooperation. The reasons listed by STA for these differences are:

(1) Difference in German and Japanese approaches to international cooperation due to geographical factors;

(2) Japan finds it difficult to consider international cooperation in application-oriented fields in which Japan has high technological standards.

The German survey results indicated that some felt Japan's R&D level in the "explication" stage was lower than those of the United States and Germany. This result is in agreement with Japanese experts' self-assessment. Evaluations by both countries support the fact that Japan will need to devote greater effort in basic research in the future.

Japan, Russia To Cooperate on Science and Technology Areas

94FE0707C Tokyo NIHON KEIZAI SHIMBUN in Japanese 28 May 94 p 11

[Text] At the Second Russo-Japan Science and Technology Cooperation Committee Meeting held in Tokyo from May 25 to 27, the governments of Japan and Russia agreed to establish cooperative arrangements among their research organizations in connection with 36 selected research themes, including those in the material technology field. New areas of research cooperation are "material science technology," "biotechnology," and "basic chemistry." When these are added to the existing 12 areas, including "space," "plasma physics" and "nuclear fusion," the total number of the areas is 30. As new research themes, the following three have been selected: (1) "research in atomic nucleus of the limited existence due to excess neutrons" undertaken by the Institute of Physical and Chemical Research; (2) "the satellite observation of radio waves as a precursory phenomenon of earthquake in predicting earthquake,"

proposed by Russia; and in the biotechnological area, "genetic engineering of microalgae for production of useful materials."

Japanese Major Economic Newspaper Reports U.S. Techno Nationalism Trend

94FE0707D Tokyo NIHON KEIZAI SHIMBUN in Japanese 16 May 94 p 15

[Text]

Exclusion of Foreign Companies from Government-Sponsored New Projects

Signs of rising "techno nationalism" in both governmental and business sectors of the United States increasingly are becoming evident in recent years. This is reflected in recent government-assisted R&D projects which have begun accepting only U.S. businesses as qualified applicants. At the same time, we are beginning to see the cases of the U.S. research organizations receiving government assistance electing to go overseas so that their research efforts can be combined with those of Japanese and other foreign companies. Moreover, increasingly the United States is placing restrictions on use of patents by foreign firms. What the industrial, governmental, and academic sectors are aiming for is to stop technology drain to overseas countries. The danger of such an action is that this may lead to a protectionist measure designed to fence in U.S. technologies, making them inaccessible to outsiders.

Joint Private Sector Research Also Restricted

Eisai Co., Ltd., recently acquired from Harvard University the right to use a patent for a processing technology designed to synthesize a candidate substance for cancer treatment. The university, however, added a proviso that any carcinostatic substance developed using this patented technology "must be produced in the United States."

In the case of a Swiss pharmaceutical manufacturer, [Sand], only after the company had agreed to sign a joint research contract with a non-profit research foundation, Scripps Institution (California), at the end of 1992 that it was able to obtain the use of the patent. However, in 1993, claiming that some part of the contents of the contract may constitute violation to the law, B. Healy, the then director of the U.S National Institute of Health, pressed Sand to review the contract. The reason for this was that "the contract allows Sand to take Scripps' research findings out of the United States to Switzerland and other parts of the world where fruits of research can be utilized. This means that the contract does not serve the best interests of the United States." Subsequently, Sand had revised the contract. U.S. Congress and Government have yet to approve the modified contract.

General Motors, Ford, and Chrysler jointly established a consortium known as USCAR. At this stage, no foreign companies are allowed to participate in the consortium. Another consortium organized with the participation of 28 companies representing the United States, i.e., AT&T, is designed to develop basic technologies for information super highway; this consortium also hangs out an off-limit-to-foreign-company sign.

Although MITI's Agency for Industrial Science and Technology (AIST) opened the national project, "The R&D Project of Basic Technologies for Future Industries," to foreign companies, participation in such national projects as DDO's military-to-civilian conversion project, the "Technology Reinvestment Plan," and the Department of Commerce's "Advanced Technology Plan," is limited to U.S. companies.

The minimum requirement for accepting a foreign capital company in the United States as a U.S. firms is a provision stating, "both research laboratory and production base must be in the United States." The strategy used by Japanese companies in the past, viz., to provide American universities with necessary funds and receive in return research results which then would be used in Japan, no longer works. Even joint developments with American universities will become difficult unless companies have a research base [illegible] in the United States.

NEC's North American research institute, which celebrated its fifth anniversary this month, is a basic research institute built 5 years ago, anticipating technological frictions which may occur at some point in the future. Today, when techno nationalism is raising its head in the United States, the result achieved by this NEC North American research institute is worthy of our attention as a test case.

Honda Motor Co., on the other hand, had been conducting research jointly with the University of Michigan in the field of advanced material development. In order to test its performance, the company even prototyped a test plane. The test flight, however, was not open even to local mass media. This was based on the consideration that "the media may misinterpret this as Honda's attempt to enter the U.S. aerospace market, causing further frictions in U.S.-Japan relationships." As seen by this example, the U.S.-Japan relationship involving technology is increasingly becoming difficult.

JRDC Selects Research Leaders for Precursory Research for Embryonic Science and Technology Program

94FE0707E Tokyo NIKKAN KOGYO SHIMBUN in Japanese 12 May 94 p 5

[Text] The Research Development Corporation of Japan (JRDC) announced the names of research areas and leaders for the 1994 "Precursory Research for Embryonic Science and Technology Program," a project designed to foster creative individual research. The program will start in October 1994, with the recruitment of researchers beginning almost immediately by JRDC.

The three research areas and researchers serving as leaders are as follows: "Heredity and Change" (Kumao Toshima, Director of Geriatric Disease Center), "Intelligence and Its Structure" (Ryoji Suzuki, Director of Human Information System Research Institute, Kanazawa Institute of Technology), and "Field and Reaction" (Akio Yoshimori, Professor of Engineering, Okayama University of Science). Thirty researchers will be recruited to cover 3 research areas. Deadline for application is set for June 30, 1994.

The Precursory Research for Embryonic Science and Technology Program was established in October 1991. Its objectives are to promote basic research designed to make the most of unique creativity of individual researchers so that pioneering science and technology will be given a chance to get started. This is an individual research setup designed to provide researchers—who are recruited and selected—currently conducting original research in the areas specified by JRDC, with an environment which allows them to carry out research in relative freedom. It is possible for individual researchers to do their work in research organizations of their choice. The description of research in the three areas is as follows:

The research area, "heredity and change," deals with changes, such as duplication, mutation, rapid viral change, and carcinogenesis, appearing as genetic duplication, cell multiplication, histo- and organ-regeneration, and reproduction of individual bodies. Mr. Toshima, who is a leader in this area, specializes in virology.

The research area, "intelligence and its structure," constitutes research in intelligent information processing engineering, encompassing information-transmission material acting as an intermediary of information passing between neurons and receptors, as well as the structure and formation of the brain and neural systems, interrelation of neurons, representational forms of information, information processing systems, logic elements, and circuit systems. Mr. Suzuki, a leader, specializes in bio-information engineering.

The research area, "field and reaction," deals with explication of molecular behavior in physical and chemical fields as well as in bio entities, change in state, interactions, and a functional field design. Mr. Yoshimori, a leader, specializes in surface materials.

JRDC will hold several informational meetings concerning the recruitment of researchers at the following places and times: June 8, 2:00 p.m., Tsukuba Research Center located at Amakubo, Tsukuba City, Ibaraki Prefecture; June 10 and 18, 2:00 p.m., Science Building, 7th floor, located at Nagatacho, Chiyoda-ku, Tokyo; and June 13, 2:00 p.m., Osaka Science and Technology Center, located at Nishi-ku, Osaka.

Superconductivity

Superconductivity Technology for Electric Power Apparatuses

43070091A Tokyo JAPAN 21ST in English Jun 94 pp 52-55

[Article by Masatoshi Nishikawa, director, New Sunshine Program, Promotion Headquarters, Agency of Industrial Science and Technology, MITI: "Superconductivity Technology for Electric Power Apparatuses—Outline of the Project for Superconductivity Technology for Electric Power Apparatuses Under the New Sunshine Program—"]

[Text]

1. Outline of Research and Development

In Japan, the expansion and construction of power generation facilities and power transmission and substation facilities have been carried out to cope with increasing demand of electricity. In the process, some problems are cropping up, such as difficulties related to securing land for construction of transmission lines, increase in the power losses, and guaranteeing the stability of the power systems in view of the increasing capacity and the remote location of power sources. In order to solve the problems effectively, it is necessary to realize high efficiency, high density and high stability of power systems, and the promotion of introduction of superconductivity technology into electric power apparatuses has been attempted as a means for implementing these improvements. In this project, R&D have been conducted for the application of superconductivity technology for power apparatuses. Aiming at making a highly efficient, smaller and lighter generator, which guarantees high stability of the power system, 70 MW class superconducting generators (model type) are being developed within the 11 years from fiscal 1988 to fiscal 1998. Besides development of the generator, R&D is also under way for metal-based superconductors and oxide-based superconductors for AC and DC application and for elementary technology for oil-free type refrigerating system (improved type). This article reports on the superconducting generator (Figure 1), which is the main theme in this project.

2. Merits of the Introduction of Superconducting Generator

A superconducting generator has the following advantages over existing generators:

1) Improvement in efficiency (0.5-1%);

2) Smaller in size and lighter in weight;

3) Improved stability of electric power system.

(synchronous reactance is 1/2-1/5 that of existing generators).

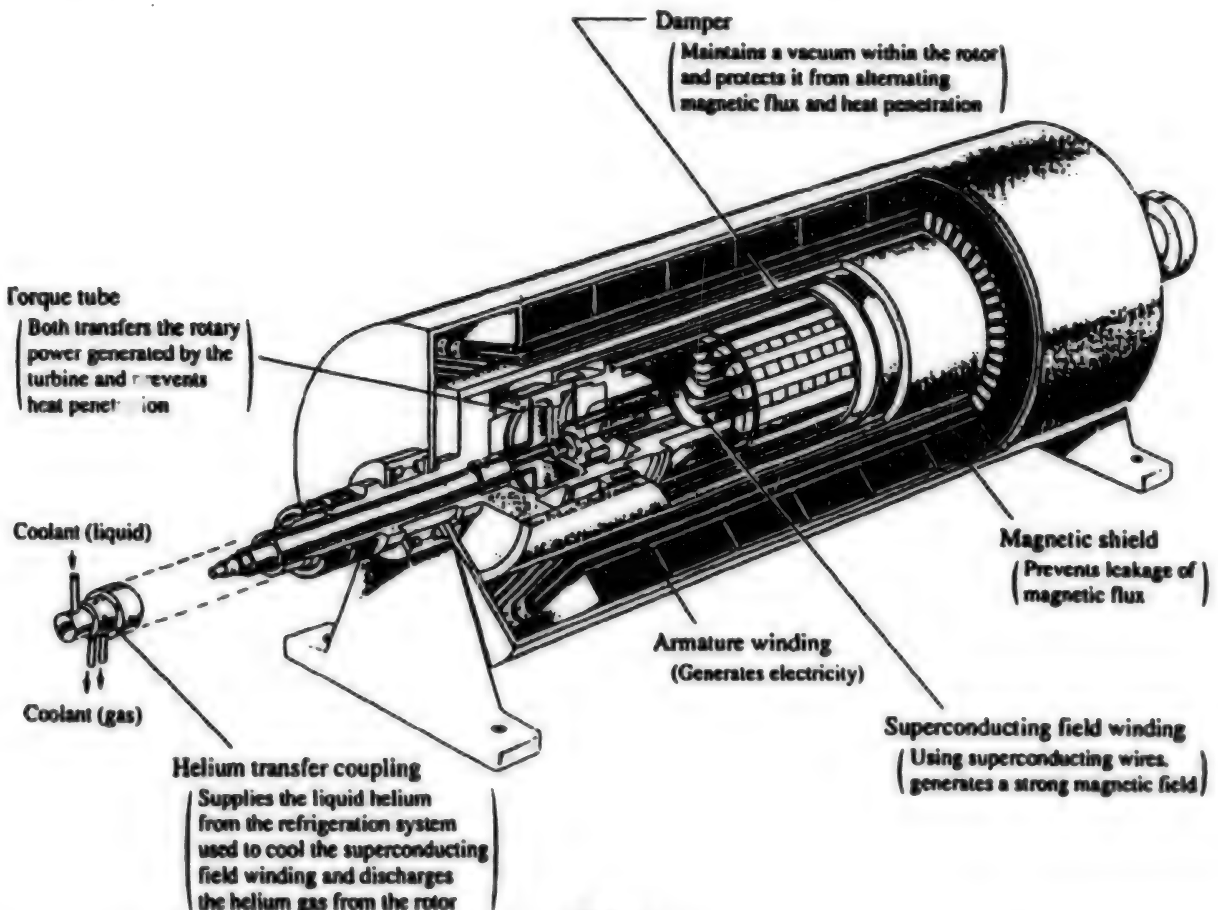


Figure 1.

The following results are expected from the above. Firstly, improving the efficiency of the generator results in energy-saving (saving of fuel cost) and reduction in CO_2 emission.

Secondly, a smaller and lighter generator will serve to save materials and space. It will enable a generator the same size as existing units to have a much larger output. As a result, it will enable manufacturing of a large-capacity generator (with a capacity twice that of existing units), which has hitherto been precluded by reasons of weight and mechanical strength.

Thirdly, a lower synchronous reactance leads to stability of the electric power system, which in turn extends the permissible level of power transmission to 1.3-1.5 times the existing limit; it will virtually save installation of many power plants and transmission lines.

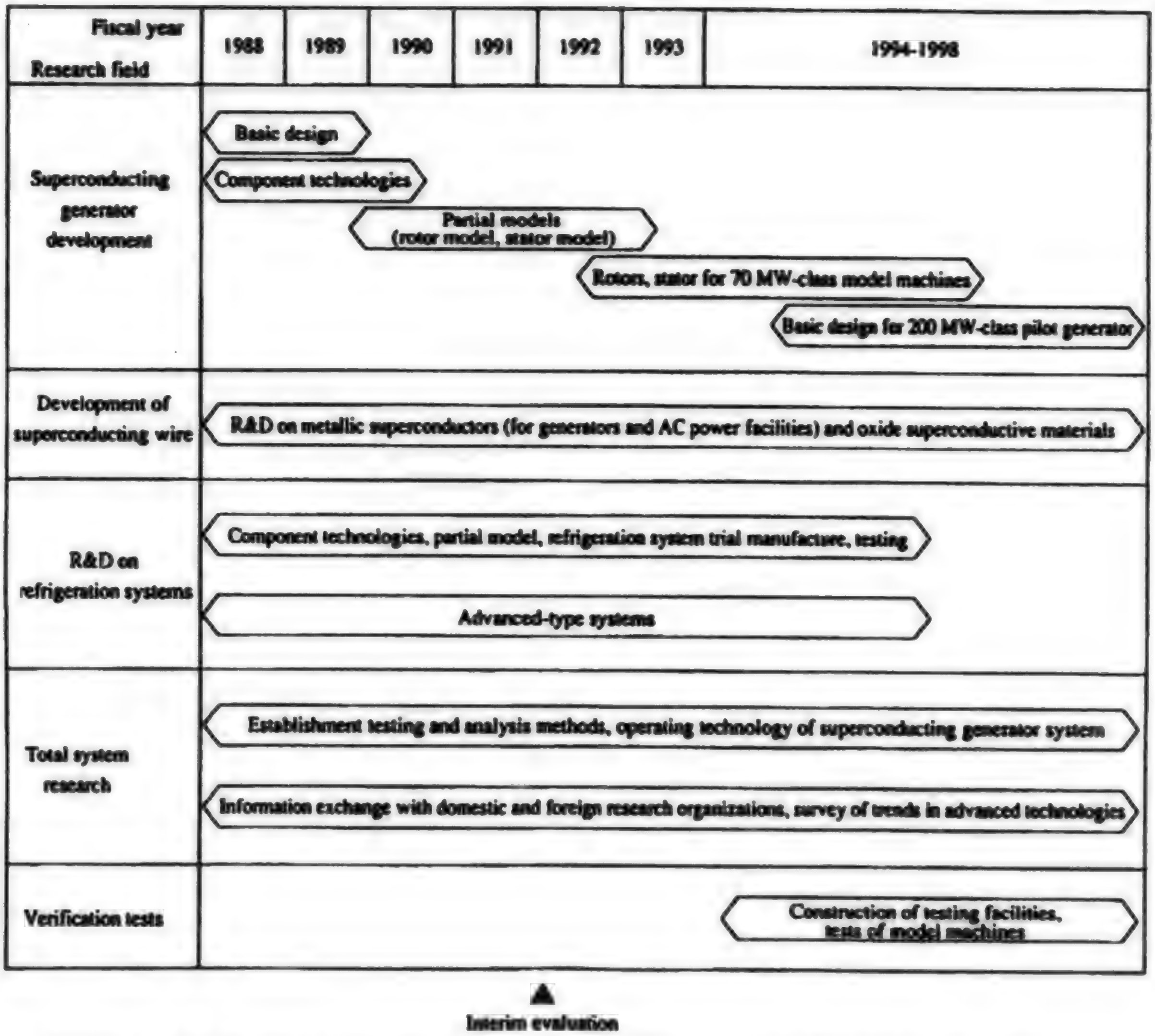
As stated above, a superconducting generators will serve effectively to cope with the increasing demand for electricity.

3. Present Development Stage of Superconducting Generator

The schedule of R&D is shown in Figure 2. The R&D on the elementary technology has been completed and manufacturing of the 70 MW class model generator has started. The models are due to be tested for field verification at Osaka Power Plant of the Kansai Electric Power Co., Ltd. to be conducted for 3 years beginning in 1996.

The parameters of the 70 MW class model are shown in Table 1. Two kinds of rotors of a low response speed type model and a rotor of a high response speed type model will be manufactured. One stator, common available for the three kinds of rotors, will be manufactured.

For the superconductors for field winding for the low response type generator, a high-stability type superconductor and a high-current-density type superconductor have been respectively selected. In selecting these superconductors, characteristic tests have been performed under compressive stress, simulating actual working condition, and we have confirmed their mechanical soundness and the soundness of their superconducting characteristics.



* In March 1993, the R&D period, having begun in 1988, was extended by three years, from an eight-to an eleven-year period.

Figure 2. Research and Development Schedule

For the high-stability type superconductor, a high-purity aluminum is used as stabilizer, so that the region of a normal state caused by turbulence in the system can be quickly restored to a superconducting state; the aluminum is separated with CuNi. With these devices in the structure of conductors, the alternate current loss has decreased and they have met the required specifications. For the development of high-current-density conductors for superconducting generators, long durability and the working conditions of intense centrifugal force and high magnetic field have been taken into consideration. In addition, superconductors have been stiffened by lowering the void fraction (the rate of void space in the stranded wire conductor) when the superconductors were formed. With these measure, development of the required specifications for superconductors has been achieved.

The development of low [AC] loss-rate superconductors selected for the high-response-speed type generator aims at achieving high stability against system turbulence. In order to attain reduction of AC loss and high current density at the same time, fine double stranded wires are used, copper ratio has been increased for the improvement of stability, and technologies for manufacturing long double-stranded wires and for lowering void fraction for increased stiffness of superconductors have been developed to fulfill the required specifications. the cross-section of the superconductors is at the 20-28 mm^2 level,

where the rated current of 3000 A passes through, i.e., the current of about 150 A passes per mm^2.

Besides the above, many elementary technologies have been developed such as for dampers and structures that are resistant to heat contraction, and analyses have been made on magnetic flux distribution of field winding, stress on rotors and stators, and temperature distribution in rotors with the partial models prepared with the developed elementary technology.

To completely test the superconducting generators and to verify their capacity, it is necessary that they are incorporated in the actual electric power system, and development of a pilot plant is indispensable. Field verification tests of the model generator are, therefore, anxiously awaited in hopes that they will materialize satisfactory results.

4. Conclusion

Further efforts in R&D and more breakthroughs will be required before superconducting generators are introduced to the actual electric power system for practical application. The generator must be so reliable as to convince power companies of its safety.

In view of the future growth of demand for electricity, generators with large transmission capacity should be attractive to the power companies. An improvement in efficiency of on one percent cannot be neglected. Certain good results have already been obtained in the elementary technology. When its superior quality and reliability are, verified through field verification tests, the superconducting generator will be established as a technology that will contribute greatly to the solution of various energy and environmental problems in the future.

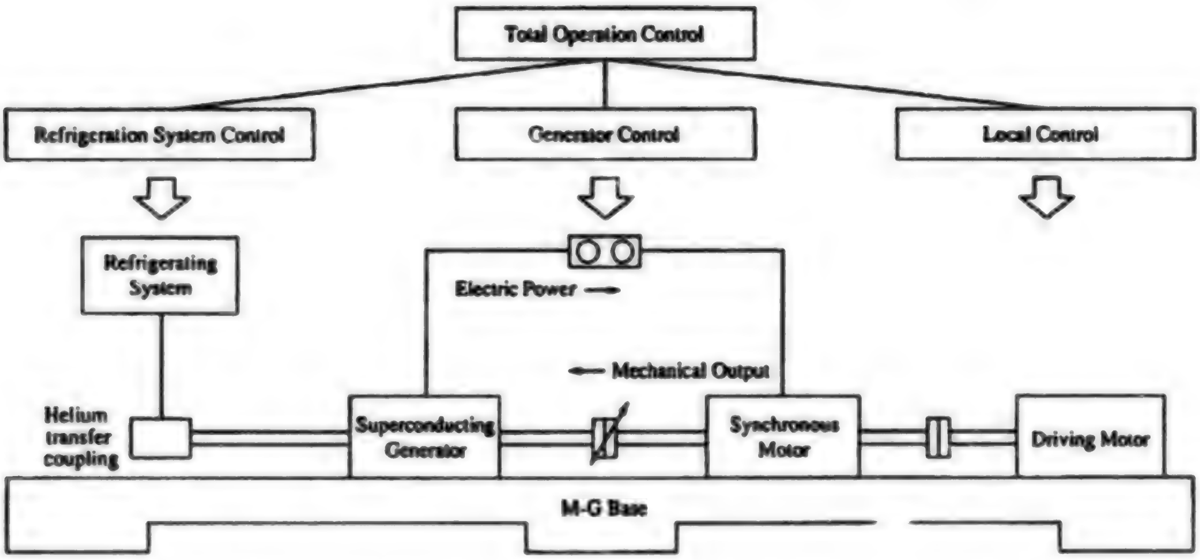


Figure 3. Field Verification Test System of Model Generator (M-G System)

Table 1. Main Parameters of 70 MW Class Model Generator

		Low Response Speed Type A	Low Response Speed Type B	High Reponse Speed Type
Main parameters	Capacity MVA	83	83	73
	Voltage kW	10	10	10
	Current A	4,792	4,792	4,215
	Synchronous reactance p.u.	0.35	0.35	0.45
	Field current (rating) A	3,000	3,000	3,200
	Maximum flux density T	4.8	5.5	6
	Outside diameter of rotor/mm	880	870	885
	Length of magnetic shield/mm	1,500	1,500	1,500
Superconducting field winding		High Stability Type	High current Density Type	Low Loss Type
Rotor Structure Room Temperature Damper Thermal Shrinkage Absorption		Single layered Type Double Bearing	Squirrel Cage Type Flexible Disk	Three layered Type Flexible Support
Stator Structure		Air-Gap Winding/[Double Transposing Conductor]/Water Coolin System		

Development of Superconducting Wire Materials Oriented to Practical Application

43070091B Tokyo JAPAN 21ST in English Jun 94 p 56

[Article by Masaki Hirano, director, Energy Technology Promotion Office, Public Utilities Department, Agency of Natural Resources and Energy, MITI]

[Text]

1. Significance of the Technical Development of SMES

In recent years non-industrial power consumption has grown steeply in Japan, and this tendency is expected to continue unabated in the future. Industrial consumption is also changing from the previous pattern of basic materials industries operating continuously day and night to that of processing and assembly industries that operate only in the daytime.

This consumption pattern has brought about an appreciable gap of power consumption between daytime and night, and an especially great seasonal gap with peak consumption during summer in a Japan characterized by high humidity and high summer temperatures. How to cope with the consumption upsurge during the summer season has become an important problem for the power industry. When the mean summer temperature rises by only 1°C in Japan, electric power consumption shoots up by more than 4 GW.

This demand pattern not only disturbs the stability of energy demand and supply, but also leads to rising costs of the electric power supply due to the low availability factor of power generation equipment. The emergence of state-of-the-art technologies and the arrival of the high information-oriented society have heightened the demand for highly reliable electric power supply. The power transmission network must incorporate a system that is actuated promptly in time of accident. Pumped storage electric power generation was once regarded as a promising remedy for maintaining comprehensive economical operation of conventional power facilities and suitable power sources during emergencies. However, this system has rapidly been losing its usefulness since suitable locations for pumped storage plants are no longer available. The development of an alternative power storage technology is urgently demanded.

In the meantime, the superconductive magnetic energy storage or SMES, utilizing outstanding features of superconductivity, has emerged as a possible technical breakthrough for the solution of this problem. First, SMES is hoped to achieve a very high power storage efficiency of over 90% as against 70% of the previous pumped storage system. Second, SMES with its extremely quick response is expected to cope with abrupt changes. Furthermore, this power storage system has a much higher location flexibility than the pumped storage plant and a relatively small system can be installed in the immediate vicinity of the consuming area.

2. Present Technical Development Situation of SMES

ISTEC (International Superconductivity Technology Center) is carrying out at present the SMES elementary technology, which started in 1991 as a commissioned project of the Ministry of International Trade and Industry.

The project is aimed at establishing the elementary technology for constructing a SMES pilot plant with a rated storage capacity of 100 kWh. The intermediate evaluation will be made in about July of 1994 after performing testing and evaluation of superconducting materials and research on optimal systems. It will be followed by the trial manufacture and testing of the main equipment including the superconductive coil. The total development cost is expected to amount to about ¥6,500 million.

The main equipment envisaged in the development of elementary technology includes the permanent current

Table 1. Development of SMES Elementary Technology

Fiscal year	1991	1992	1993	1994	1995	1996
Development of elementary equipment	Technology study, partial trial manufacture, testing and evaluation			Intermediate evaluation	Design, trial manufacture, testing and evaluation	
System research	Study of the optimal system and of the effect of introducing the system				Trial manufacture and testing of partial models	
Testing and evaluation of materials	Study of the methods for testing and evaluation					

switch, the quench protecting device, the DC breaker, the DC-AC converter and the superconductive coil. The schedule of the elementary technology development project and the specifications of the pilot plant are summarized in Tables 1 and 2.

Table 2. Specifications of the Pilot Plant

Storage capacity	100 kWh
Converter output	40 MW
Current	20 kA
Voltage	20 kV
Coil form	Toroid

Electrotechnical Lab's Research of Superconductivity for Electric Power Apparatuses

43070091C Tokyo JAPAN 21ST in English Jun 94 pp 57-61

[Article by Toshitada Onishi, formerly with Electrotechnical Laboratory and presently professor at Hokkaido University]

[Text]

1. Preface

Applied research of a met[illegible]perconductor is considerably mature. Recently [illegible]alled research for practical use has been unde[illegible] realize superconducting equipment for practical [illegible] particular, application of the superconductivity technology to electric power apparatuses requires a high reliability such as magnets for nuclear fusion, generators, energy storing magnets, fault current limiters, and transformers. It is important to establish the reliability in the research for practical use. This is strongly expected of national laboratories as well as of the basic research of universities. Among the basic research on various types of superconductivity technology for electric power apparatuses performed by the group comprised of the author and others in Electrotechnical Laboratory, where the author had been engaged up to March 31, 1994, the following are the fields of basic research; research on the stability of a superconducting rotating magnet, development of a superconducting fault current limiter, and basic research on a superconducting wire.

2. Research on Superconducting Generators and Related Matters

A 70,000 kW-class model superconducting generator has been developed as a project of the Agency of Industrial Science and Technology since 1988 in order to establish the elementary technology and the system technology necessary for a 20,000 kW-class pilot superconducting generator.

Securing a high stability of a rotary superconducting magnet for generating a rotating magnetic field is one of the most important problems to be solved. At the Electrotechnical Laboratory, testing equipment was developed for evaluating the stability of a superconducting magnet which rotates at a high speed and performs basic research to establish a design criterion for stability. Hitherto, they have measured the expansion velocity of the portion changed to the normal conducting state of a superconducting wire of a magnet rotating at a speed of up to 3,600 rpm, that is, the propagating velocity of the normal zone by forcibly heating a part of the superconducting wire or by measuring the velocity returning to the superconducting state and comparing the velocity with a calculated value.[1]

2.1 Outline of testing equipment

The testing equipment comprises a superconducting rotary magnet, a multiple cylindrical rotor, a slip ring for transferring a sensor signal to a recorder, a driving motor, a liquid helium transfer coupling, a magnetic shield to prevent a rotating magnetic field from leaking to the outside, a bearing lubrication system, and an evacuation system.

Figure 1 shows the appearance of the equipment. For main parameters of the equipment, the overall length of the equipment is approximately 6 m, the length of the rotor is approximately 1.8 m, the outside diameter of the

rotor is approximately 50 cm, and the length of the superconducting coil is approximately 80 cm.

Moreover, the rated current-carrying capacity is 2,000 A and the centrifugal force produced at the rated rotational speed of 3,600 rpm is 2,000 g. Photo 1 [not reproduced] shows a general view of the equipment.

2.2 Test results and analysis

The rotor magnet consists of three slots per pole. Two slots among them include a coil for a backup magnetic field and the one remaining slot includes a test coil for testing the stability. Both the former and latter coils are connected in series and up to 2,000 A can be applied to them. In this case, the maximum field of 4T is generated at a winding comer. The test coil is formed like a race track and the test for stability was performed at its straight portion. The conductor used for the test is a stranded wire constituted by forming 12 strands (diameter of 0.7 mm each) made of NbTi/Cu/CuNi and NbTi/Cu so that the cross section of the arranged strands is a rectangle and its rated current density is approximately 385 A/mm^2. Figure 2 shows a sectional view of the conductor. The test was performed by heating a part of a superconducting wire constituting the coil rotating at a high speed by a heater to forcibly generate a normal zone and measuring the zone expansion velocity, that is, the propagating velocity of the normal zone.

Figures 3(a) and 3(b) show their structures: Figure 3(a) shows a case of an N pole (conductor structure: NbTi/Cu/CuNi) and Figure 3(b) shows a case of an S pole (conductor structure, NbTi/Cu). From these test results, the following points are clarified:

(1) The propagating velocity increases as the applied current increases and the dependency of the rotational speed is not very large;

(2) The propagating velocity of the normal zone greatly differs depending on whether an electric insulation

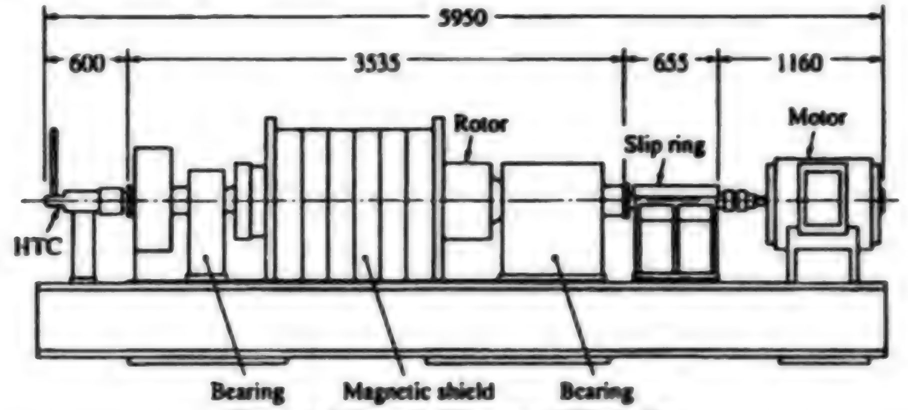


Figure 1. Schematic Diagram of Whole Rotor

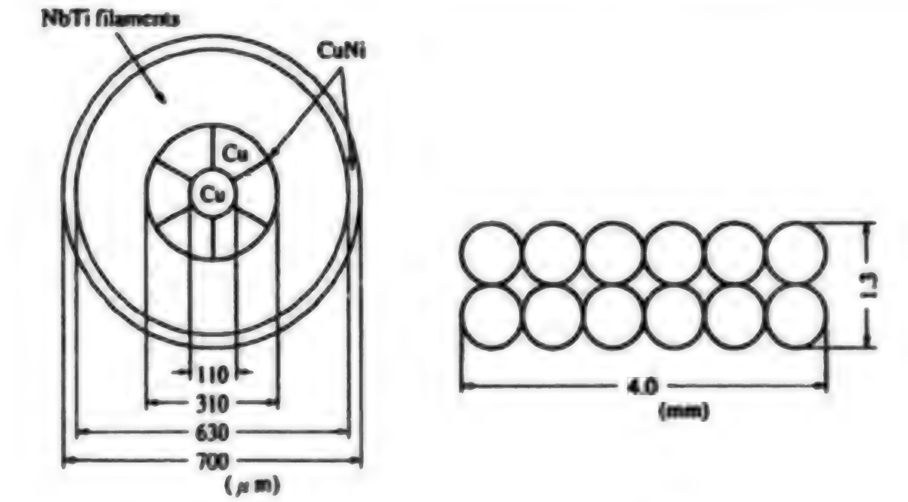


Figure 2. Cross Sections of a Strand (a), and Conductor (b)

(Formval) is present on the conductor surface, which increases when the electric insulation is present on it;

(3) When the entire cross section of a superconducting wire is equal, the minimum propagating current (the minimum value of current when normal zone expands) increases as the quantity of copper for stabilization increases;

(4) The value of the minimum propagating current increases as the rotational speed increases because heat transfer from the conductor surface is improved as the rotational speed increases.

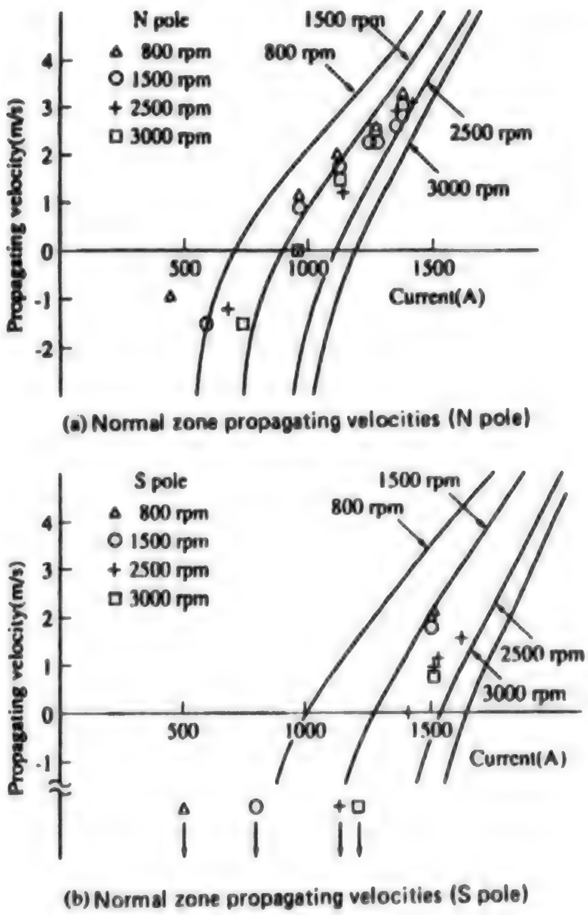


Figure 3. (a) Normal Zone Propagating Velocities (N pole); (b): Normal Zone Propagating Velocities (S pole)

A solid line in Figure 3 represents the value of propagating speed of normal zone calculated by L. Dresner, by which a measured value can be preferably explained comparatively. The stability of a rotary magnet was tested by developing a testing equipment simulating the magnet of an actual scale. As a result of evaluating the stability according to the concept of the minimum propagating current and comparing the test result with the analysis result, both results coincide well with each other. Though the results are not shown here, a conductor structure to increase the minimum propagating current is theoretically studied according to the results. As a result, it is clarified that 200 A/mm^2 at 5T is possible as the average current density of the minimum propagating current of the magnet. Thereby, successful prospects are obtained to establish a rotor-magnet stability design criterion based on the minimum propagating current.

Scheduled is a study on the stability by assuming the movement of superconducting wire and the thermal disturbances, including an alternating current loss.

3. Research and Development of Superconducting Fault Current limiter[1,2]

Because transmission voltages are raised and transmission routes are multiplied, overcurrent prevention measures for a short-circuit fault also become important. However, no proper technique has been found. Therefore, it is strongly requested to develop a current-limiting device using a superconducting material. A system utilizing the superconducting/normal conducting transition is widely researched as a superconducting fault current limiter. However, those in the Electrotechnical Laboratory devised magnetic-shield-type superconducting fault current limiter actively using the flux jump characteristic, which is a principle completely different from that of the above system, and are testing a prototype of the fault current limiter. Experiment and analysis results using a NbTi cylinder operating at the liquid helium temperature as a magnetic-shield body have already been reported.[2] The characteristic test of a fault current limiter using a Bi-based oxide superconductor tested at the liquid nitrogen temperature is described below.

3.1 Structure and principle of fault current limiter

Figure 4 shows fault current limiter having a structure in which a superconducting cylinder is set around an iron core to shield a magnetic flux. A copper coil is wound on the cylinder. When the device is actually used, the coil is connected to an electric power system in series.

For the basic principle, the magnetic flux generated by the coil under the normal state of the system does not interlink with the iron core because it is shielded by the superconducting cylinder. Therefore, the inductance of the coil is very small. However, if trouble occurs in the system, the superconducting cylinder causes a flux jump due to the magnetic field generated by the coil which is due in turn to an overcurrent and it is quenched. Therefore, almost all magnetic fluxes generated by the coil pass through the superconductor and are interlinked with the iron core. Therefore, the inductance of the coil increases extremely. A change of the impedance causes an intense current limitation.

The prototype fault current limiter is constituted by superimposing 26 Bi-oxide superconductings with an

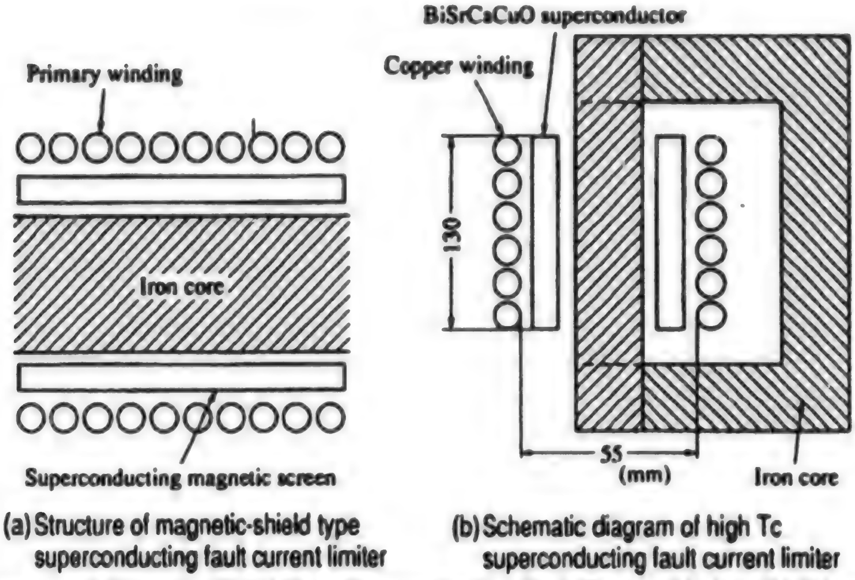


Figure 4. (a) Structure of Magnetic-Shield Type Superconducting Fault Current Limiter; (b) Schematic Diagram of High Tc Superconducting Fault Current Limiter

outside diameter of 50 mm, an inside diameter of 40 mm, and a thickness of 5 mm with a copper wire of a diameter of 1 mm densely wound around the laminate 120 times. The iron core comprises an iron core leg constituted by superimposing 41 thin silicon-steel plates with a thickness of 0.5 mm and a width of 25 mm, and an iron yoke constituted by superimposing 39 thin silicon-steel plates with the above thickness and width.

3.2 Test and study results

The test circuit shown in Figure 5 comprises a fault current limiter, a load, and a power source (50 Hz). The fault current limiter, including an iron core, is cooled in liquid nitrogen. The current limiting characteristic when both sides of the load are shorted is measured as a test simulating a system short-circuit fault. Figure 6 shows one of the results. From Figure 6, it is found that, though the circuit current suddenly increases starting with 36 A immediately after a short circuit occurs, current-limiting action occurs and the circuit current is controlled to 100 A. The ratio between input impedances before and after the current-limiting action starts is 1.4. A ratio of 1.4 is a very small value, though the ratio must be large enough in the case of a device to be practically used. This is probably because the superconductor is under a magnetic flux flow state without completely causing normal transition.

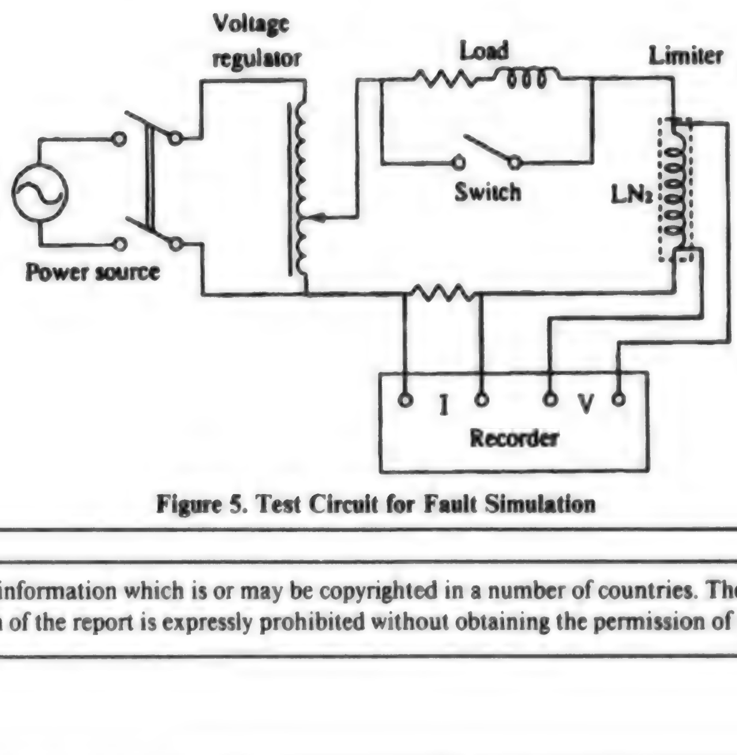


Figure 5. Test Circuit for Fault Simulation

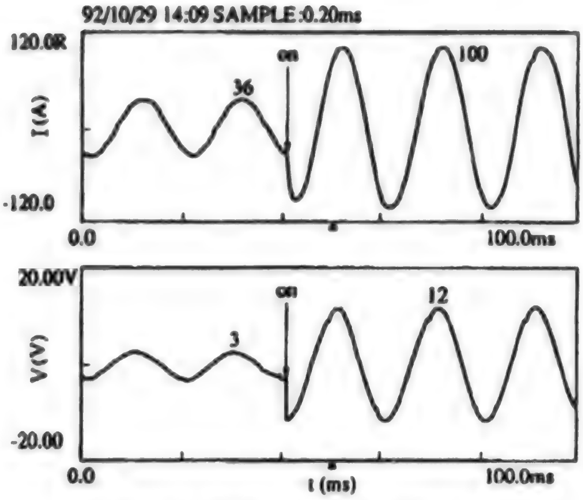


Figure 6. Result of Fault Simulation

Scheduled is the development of a fault current limiter which operates at the liquid nitrogen temperature by solving these problems.

4. Research of High-Magnetic-Field Superconducting Pulse Magnet[3]

A more-than-10T-class high-magnetic-field pulse magnet generally uses a superconducting material such as Nb_3Sn. However, because intense static and dynamic electromagnetic forces are generated during vigorous operation, a very strong characteristic is requested for a superconducting wire to be coiled. Because a wire manufactured by the existing bronze method cannot withstand the electromagnetic forces, it is normally reinforced with an external reinforcement or by placing it in a stainless-steel conduit. Those in the Electrotechnical Laboratory proposed, as shown in Figure 7, a very-strong filament wire having a structure in which a fine, very strong core (made of tungsten fiber, alumina fiber, or carbon fiber) is covered with a superconducting layer which is in turn clad with copper for stabilization as a method for reinforcing the Nb_3Sn wire in order to solve the problems, and manufacture the wire on trial and evaluate and research the characteristics of the cable. The cable is manufactured by depositing bronze with a proper thickness on a core by means of radio-frequency sputtering while rotating it, forming a niobium film on the bronze, and finally depositing copper on the film by means of sputtering, and thereafter heat-treating the core at approximately 7000°C. Photo 2 shows a sample made by forming a Nb_3Sn film around an alumina fiber with a diameter of 15 pm using the above method. For the normal bronze method, the characteristic is deteriorated because a compressive stress is applied to Nb_3Sn due to the difference between the thermal contraction rate of bronze serving as a matrix and that of Nb_3Sn. However, this method makes it possible to prevent the characteristic from deteriorating because both thermal contraction rates can be adjusted. For example, when tungsten-26% henium is used as a core, a result is obtained in which the highest Ic is shown when the strain applied in the direction of the wire axis from the outside is 0. By this method, a critical current density approximately equal to the critical current density by the existing bronze method is obtained present. Research is scheduled for forming the above fine wires into a large-capacity conductor.

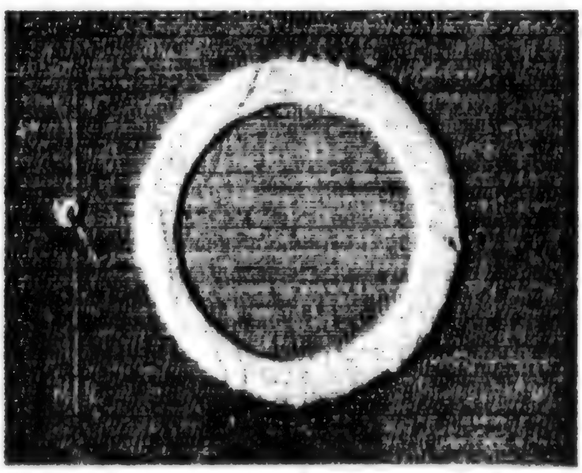
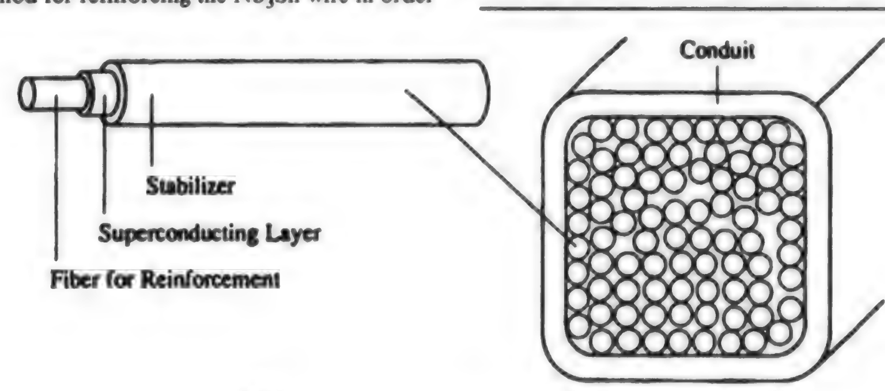


Photo 2. Alumina-Fiber-Reinforced Nb_3Sn Wire



(a) (b)

Figure 7. Fiber-Reinforced Nb_3Sn Wire

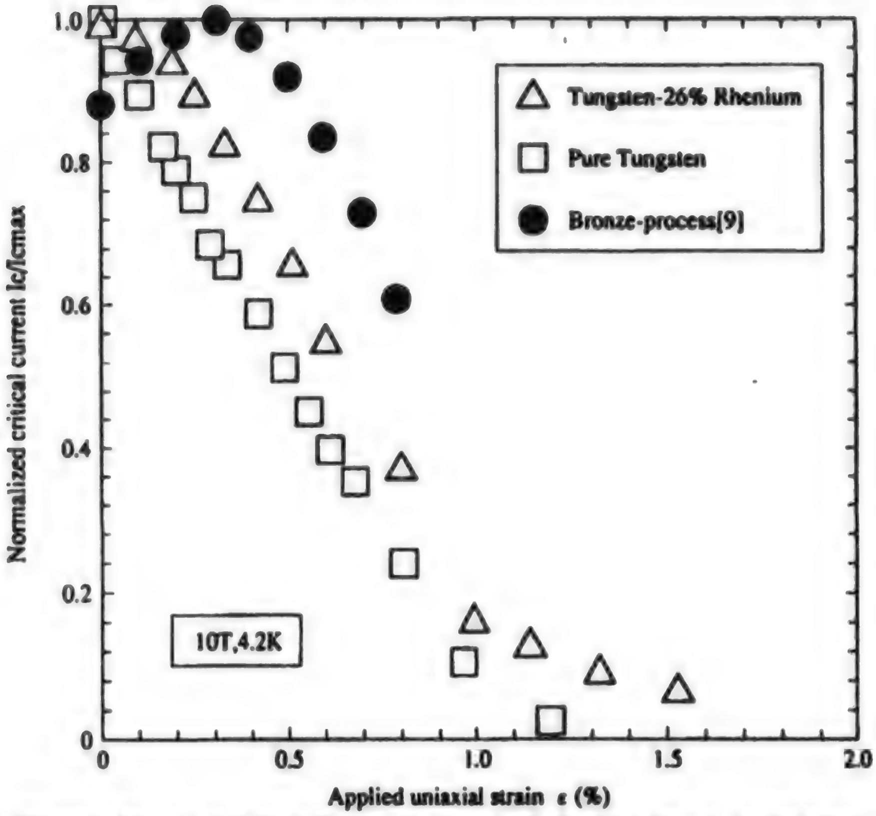


Figure 8. Change of Critical Current Density of Nb_3Sn Wire Due to Applied Strain

5. Conclusion

This is a report on some of the research performed at the Electrotechnical Laboratory where the author was principally engaged on basic techniques necessary for practically using superconductivity technology for electric power apparatuses such as superconducting generators and for improving their performance. In addition to the above, the laboratory is conducting research for systematizing a superconducting transmission cable using Nb_3Sn and for decreasing the alternating-current loss of the cable; a detailed study of the proximity effect as the research for clarifying the mechanism to decrease the loss of an alternating-current superconducting wire; and research of the superconducting high-gradient magnetic separation technique. Research is undertaken by stressing technical problems to be solved for superconductivity technology for electric power apparatuses due to applied strain which can be practically used in the above laboratory. Therefore, it is also the author's opinion that research should be performed according to the above policy in the future so as to practically use superconductivity technology for electric power apparatuses as soon as possible.

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Development of Superconductive Magnetic Energy Storage Systems

43070091D Tokyo JAPAN 21ST in English Jun 94 pp 62-65

[Article by Kazumasa Togano, director, First Research Group, National Research Institute for Metals, Science and Technology Agency]

[Text]

1. Introduction

Since the first announcement of S "high" temperature superconductivity in some metal oxides in 1986, seven years have elapsed. Following the discovery of tallium-based superconductors in 1988, the race for higher critical temperature seems to have settled down. However, the fever of exploring for new materials has been rekindled by the report of critical temperature 150 K or higher with mercury-based oxide in 1993.

On the other hand, efforts to put oxide high temperature superconductor into practical application have been actively continued. As is well known, the availability of Tc higher than liquid nitrogen temperature (77 K) has a great practical significance, which stirred up a sensational fever. The recent trend is, however, turning to the application development derived from more basic understanding of the nature of oxide high temperature superconductors. For instance, owing to the progress of cryogenic technology, intermediate temperatures between liquid helium (4.2 K) and liquid nitrogen have become obtainable with relative ease, and the application of superconductivity at these temperatures has been seriously considered.

The present paper concerns technology to make wire of oxide high temperature superconductor and the present status of its application development. One of the most important characteristics of superconductor for making wire is critical current density. The critical current density of practical level has already been obtained with bismuth-based superconductor, and basic studies on strong magnetic field generation and power transmission have already been initiated.

2. Present Status of Wire Development

The critical current density of oxide high temperature superconductor is limited by weak electrical coupling between crystal grains (weak coupling) and easiness of flux movement under applied magnetic field (flux movement causes energy loss). These problems are closely related to essential properties of these materials, such as very strong two-dimensionality and extremely short coherence length, which have made it very difficult to solve these problems.

However, owing to incessant efforts of many researchers, clues for settling these seemingly insolvable problems has been turning visible earlier than previously supposed. For instance, in yttrium-based superconductor (Y-Ba-Cu-0), the flux movement is successfully suppressed by precipitations (flux pinning), exerting excellent critical current density characteristics even under magnetic field in liquid nitrogen.

However, it seems that bismuth-based superconductor (Bi-Sr-Ca-Cu-O) is presently more advantageous for applications such as wire, because the crystal grain alignment is readily realizable, and this greatly strengthens intergrain coupling. The Bi-based superconductor can carry, therefore, current density as high as 10^4 A/cm^2 in liquid nitrogen even in polycrystalline form. This provides merits for replacing copper wires with superconducting wires, and serious studies of applying the latter to power transmission are being started.

However, it may be pointed out that the critical current density of bismuth-based superconductor drops drastically in liquid nitrogen under magnetic field. This is due to higher flux mobility in comparison to yttrium-base compound. This effect can be adequately reduced by lowering temperature, and critical current density of practical level, 10^4 A/cm^2, can be achieved in liquid helium (4.2 K) and under magnetic field higher than 20 tesla. It is attempted, therefore, to use Bi-based materials for generating high field, for the present, in liquid helium or while keeping cryogenic refrigerator operation, and some preliminary application tests have already been started.

While a number of methods have been proposed for the process of manufacturing wire, the so-called "powder-in-tube" method, processing silver pipe filled with superconductor powder is being used most widely, owing to easy availability of sufficient length and acceptable properties. Another method allowing to obtain long wire from powder materials is to coat silver tape with slurry, by dipping, prepared by mixing superconductor powder with organic binder (Figure 1). Either methods are characterized by resulting in strong crystalline orientation in bismuth-based compounds. Specific techniques to realizing grain alignment are applying mechanical stress such as rolling and pressing for (Bi, Pb)$_2$Sr$_2$Cu$_2$O$_X$ (Bi-2223) phase, and crystal growing for Bi$_2$Sr$_2$CalCu$_2$O$_x$ (Bi-2212) phase. In bismuth-based compound, weak coupling is extensively improved by this means and it becomes possible to carry adequate transport current. This is very advantageous for preparing wire materials, and for this reason, most efforts to develop superconducting wire are concentrated in Bi-based superconductor.

3. Present Status of Wire Application

As mentioned in the above, currently bismuth-based superconductor is in the limelight of application to wire. This compound is characterized by very high critical current density under high magnetic field at lower temperature, and rapid drop of current density under field as the temperature is raised. For this reason, there are currently available two ways for the application to wire materials.

The first is to use the material for generating strong field at low temperature ignoring its merit of high critical temperature. The resultant wires are to be used in liquid helium (4.2

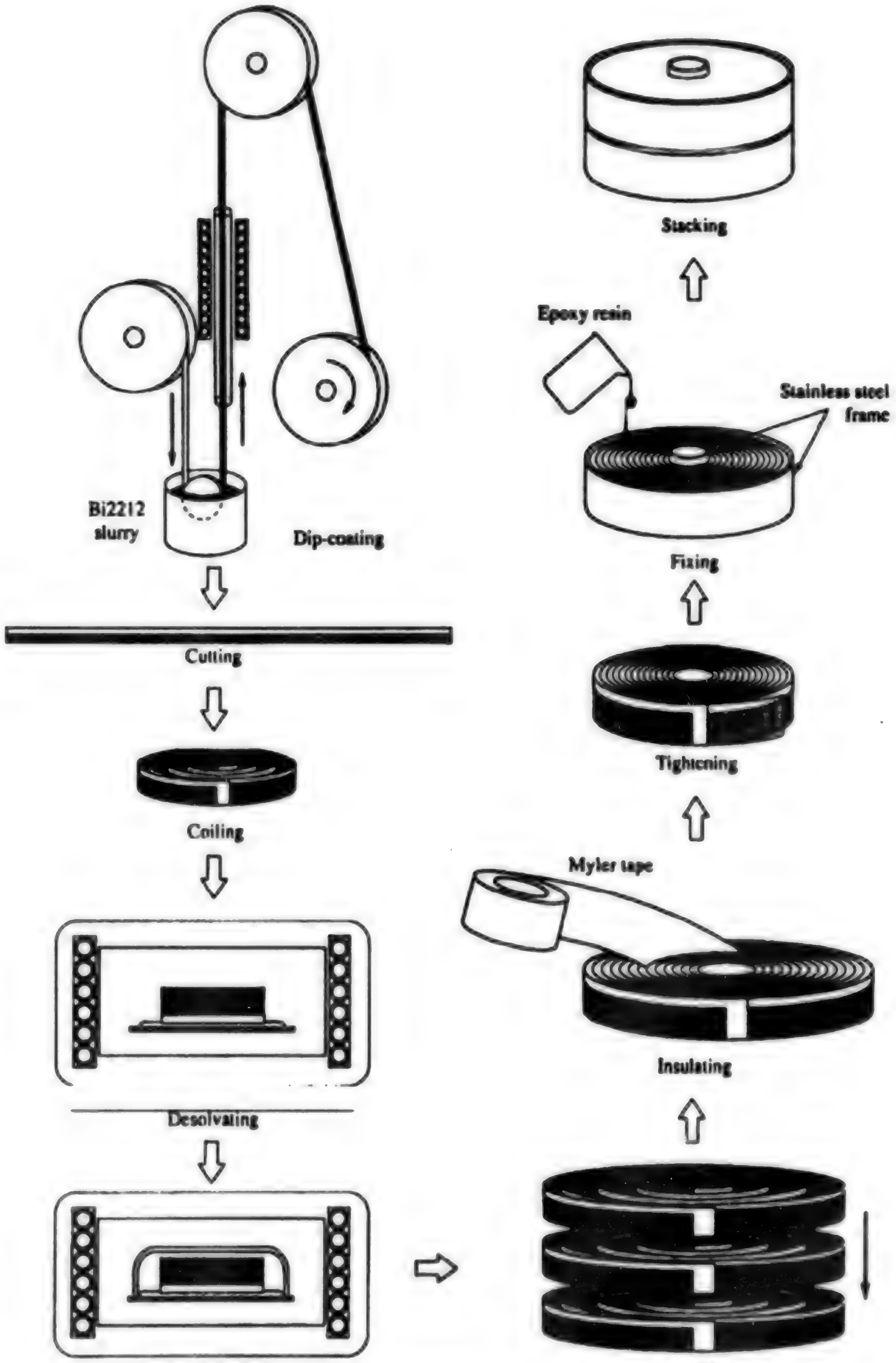


Figure 1. Process of Manufacturing Bi-2212 Tape and Coil Through the Dip-Coating Method (NRIM-Asahi Glass-Hitachi Cable)

K) or in an atmosphere kept at 30 K or lower by continued operation of cryogenic refrigerator. The second is the application to transmission cable which is rarely affected by magnetic field. In this case, wires are used in liquid nitrogen (77 K), taking advantage of high critical temperature.

a) Superconducting magnet

The application of oxide high temperature superconductor to superconducting magnet involves two methods.

The first is to generate magnetic field much higher than 20 tesla, which could not be attained by conventional superconducting magnets, by utilizing overwhelmingly higher critical field in comparison to that of practical metal superconductors, such as Nb-Ti, Nb_3Sn and others. In this case, it is imperative to use liquid helium. For the present, however, the magnet is to be constructed not by oxide superconductor alone, but in combination with conventional metal materials (Nb-Ti, Nb_3Sn) which are prepared by established manufacturing technique and enjoying much higher reliability. That is, preliminary field, as high as possible (15-20 tesla) is to be generated by using a Nb-Ti/Nb_3Sn coil, and to be further boosted by inserting an oxide coil. Testing with magnet based on this concept has already been started.

The author with his coworkers has tested with a hybrid coil consisting of existing Nb-Ti/Nb_3Sn superconducting magnet and additional coil made from Bi-2212 tape, as illustrated in Figure 2. First, the outer coil of Nb-Ti/Nb_3Sn magnet was excited to 20.8 tesla, and later the

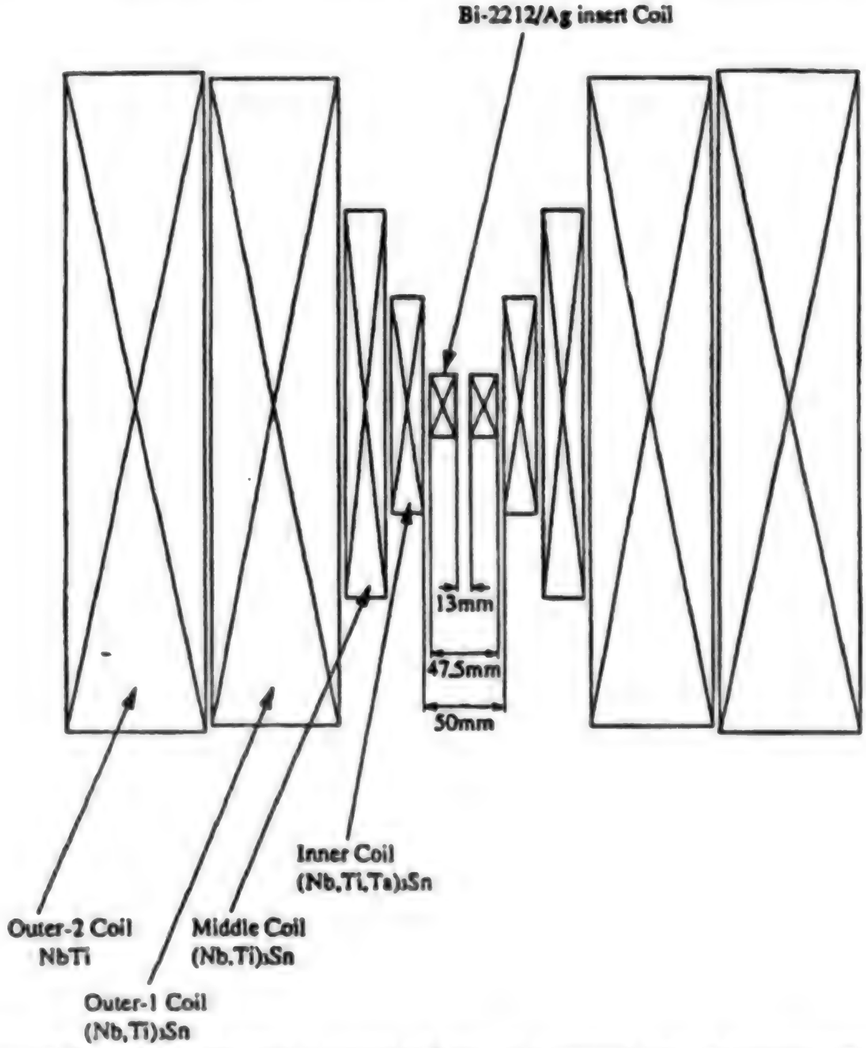
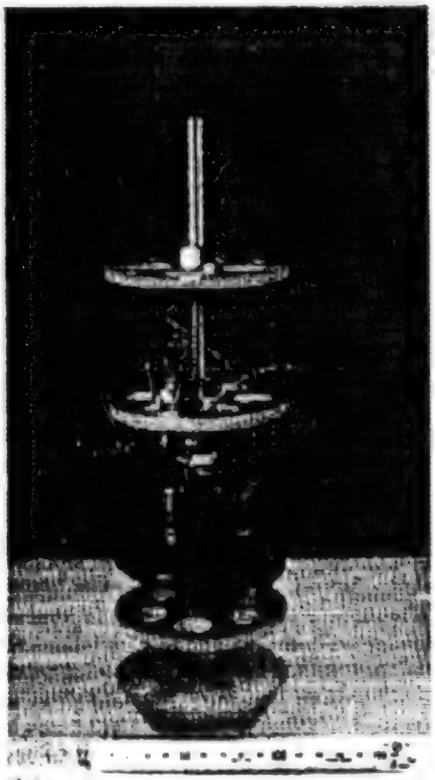


Figure 2. A Longitudinal Section Through a Hybrid Coil System Composed of Four Superconducting Coils Made From NbTi/Nb_3Sn and an Insert Coil Made From Bi-2212 Tape. This configuration provided a field of 21.5 tesla, which is the highest record ever achieved by the superconducting state (NRIM-Asahi Glass-Hitachi Cable).

oxide coil was energized. Consequently, the second coil generated additional field up to 0.7 tesla, resulting in 21.5 tesla at the center. This is the highest record of magnetic field achieved by the superconductivity alone. Currently, efforts are being made to obtain higher field on the basis of this scheme. For this purpose, an oxide coil of larger size is being trial-manufactured, as shown in Figure 3. This magnet is capable of generating field as high as 2.6 tesla in liquid helium without bias field, and belongs to the highest class among magnets ever made from oxide superconductors up to now.



Parameters of Bi-2212/Ag coil

Tape length	30 m × 2
Cross section of Bi-2212	14 μm × 12 mm × 2
Number of turns	166
Inner bore	20 mm
Inner diameter/ outer diameter	22 mm/92 mm
Potting material	epoxy

Figure 3. Main Parameters of a Superconducting Coil Made From Bi-2212 Tape. This coil generated 2.6 tesla field at 4.2 K without bias field (NRIM-Asahi Glass-Hitachi Cable).

The high field magnets surpassing 20 tesla will be applicable to studies of physical properties under high field and to the high precision nuclear magnetic resonance (NMR) spectrometer.

Another way of magnet application is to construct superconducting magnets of a few tesla through simple means without using expensive and difficult to handle liquid helium. As stated in the above, the current technology cannot provide magnets viable in liquid nitrogen, and it is necessary to cool the magnet to 20 K or so by running a cryogenic refrigerator for keeping normal operation. Some successes have already been achieved: Sumitomo Electric Industries produced 1.1 tesla in a 40mm space with superconducting wire made from Bi-2223, and Kobe Steel, Ltd., generated 0.68 tesla in an 81mm space with Bi-2212. It will give a significant practical impact if a field of a few tesla can be readily created by pressing a switch of cryogenic refrigerator. For instance, the equipment of magneto-resonance imaging (MRI) for medical care will have the operation extremely simplified, providing enormous merit.

b) Superconducting cable

The application to transmission cables which are free from magnetic field may be counted as one of the most practicable applications using liquid nitrogen. The front runner in this area is a group consisting of Tokyo Electrical Power Co., Inc., Sumitomo Electric Industries, Ltd., and Furukawa Electric Co., Ltd. This group succeeded in 1992 to transmit current as high as 2025 A through a superconducting cable 1-m long. More recently, the group announced successful preparation of 5-m cable carrying 3000 A. This cable is so flexible that it can be bent at a radius of curvature 1.3 m, allowing to be laid in the practically applicable manner.

In this way, they claim the foundation for the development of superconducting cable has been well established, and the further task will concern the peripheral technologies such as cryogenic refrigerating system.

4. Conclusion

Though studies of applying superconductor to wire is currently being pursued around bismuth-based oxides, successful preparation of superconducting wires from yttrium-based compound, which has excellent pinning effects at higher temperatures, will contribute to a great progress in the application. A bottleneck for this line of development is the problem of weak coupling. Some oxide superconductors, such as tallium- or mercury-based ones, having higher critical temperatures than those based on bismuth, are currently being studied intensively. The barrier to be overcome in this area is how to obtain grain alignment. The further progress in studies of these superconductor materials is indispensable for advancing the application of high temperature superconductors.

Furukawa Electric's Superconductivity R&D

43070091E Tokyo JAPAN 21ST in English Jun 94 pp 62-65

[Article by Yasuzo Tanaka, general manager, Metal Research Center, Furukawa Electric Co., Ltd.]

[Text]

Introduction

Furukawa Electric began research and development on superconductivity in 1963, and our long experience in nonferrous metals made it possible to begin production of superconducting wires and cables within five years.

Since then, our products have gained a worldwide reputation for high quality. With continual research and development work, the company has succeeded in developing many new types of superconducting materials and technologies, expanding our line of superconducting wires, cables, magnets and other related products to superconductivity. They have been supplied to set up makers and research institutes both within and outside of Japan, contributing to many projects around the world.

Metallic-based Superconductors

Furukawa has achieved the highest critical current density value Jc in a Nb-Ti alloy superconductor, and established the standardized fabrication process for wires used in MRI magnets and NMR spectrometers. The company was the first to commercialize multifilamentary compound superconducting wires (V_3Ga and Nb_3Sn) by the bronze process, and through this, realized sufficient reliability in high magnetic fields. The company has also commercialized the superconducting coaxial cable for an accelerator control system.

Recently a new technique for processing superconducting wire and introducing artificial pinning centers into superconducting filaments has been developed. A large number of normal metal pinning centers are embedded into NbTi superconducting filaments, and pin size, pin shape, pin interval are reduced by the extrusion and cold drawing processes to the designed values. The company has already achieved the excellent flux pinning characteristics of NbTi composites with island-shaped or ribbon-shaped Nb artificial pins. In the case of the ribbon-shaped one, a high Jc of 15,000 A/mm^2 at 2T and 4,250 A/mm^2 at 5T, 4.2 K was attained without Jc anisotropy by the introduction of Nb artificial pins into the NbTi superconductor, where the designed pin structure is composed of randomly oriented clusters of Nb/NbTi multilayers as shown in Figure 1. The Jc value for the present composite exceeded the highest Jc attained in a conventional NbTi composite with α-Ti precipitates. The maximum values were obtained when the Nb layer thickness was designed to be approximately twice the coherence length in NbTi, where the layer thickness is five to ten times the thickness of the optimized α-Ti ribbon thickness in a conventional NbTi alloy system.

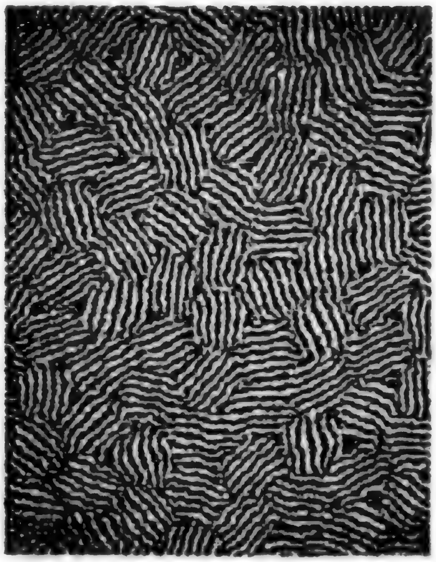


Figure 1. A Cross-Sectional view of the Artificial Pin Structure Composed of Randomly Oriented Nb/NbTi Multifilamentary Clusters

In the case of an island-shaped one, also high Jc, such as 16,100 A/mm^2 at 1T, 6,100 A/mm^2 at 3T and 2,890 A/mm^2 at 5T, 4.2 K were achieved by optimizing the pin parameters inside the NbTi filaments for ultrafine-multifilamentary NbTi superconducting wires having Nb island-type artificial pins. The obtained Jc above 0.5T are two or three times higher than in most conventional NbTi superconducting wires for AC use, because the position of the peak value of pinning-force density could be shifted in the wide range of the magnetic field by controlling the designed artificial pin parameters. On the basis of these results, the company designed and fabricated an AC superconducting solenoid magnet in collaboration with Kyushu University, as shown in Figure 2. This magnet was the first magnet wound by NbTi multifilamentary wires with artificial pins, and can generate the peak value of 2.5T at 60 Hz AC mode without quench, where the electrical capacity of the magnets corresponded to about 100 kVA.

Furukawa has joined in the project promoted by the Japan Atomic Energy Research Institute (JAERI), where the central solenoid scale model coil (CS-SMC) of the International Thermonuclear Experimental Reactor (ITER) is now being developed. The central solenoid coil should be operated at a high field of 13T, at a high current of 40 kA and with a high ramping rate of 2T/s. From the views of a high critical current and a low AC loss, the development target of the strand was determined:

i) high critical current density, non-Cu Jc:600 A/mm^2-800 A/mm^2 in the zero strain condition at 12T and at 4.2 K;

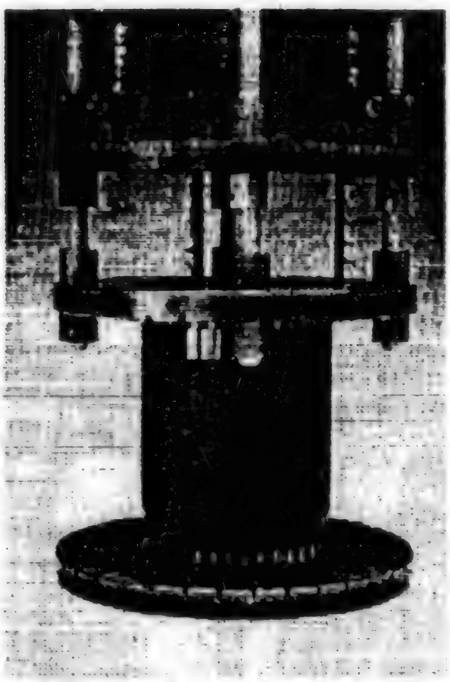


Figure 2. Photograph of the Completed AC Magnet Using the Superconducting Wire With the Island-Type Artificial Pins

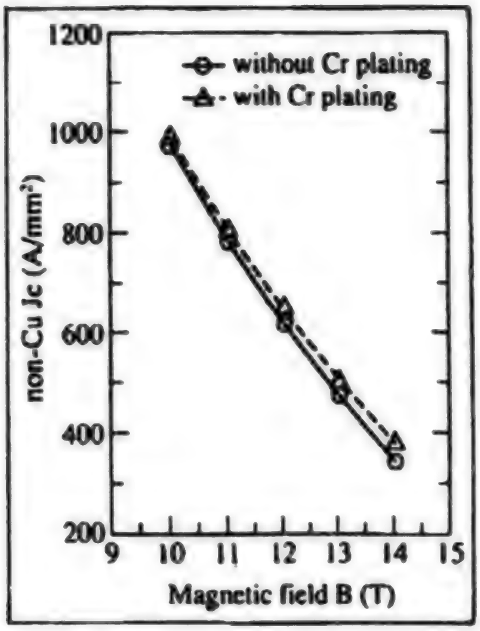


Figure 3. Critical Current Density Versus Magnetic Field of the Strand for CS-SMC Conductor

ii) low AC loss: effective filament diameter (d_{eff}) 10/μ and 200-600 mJ/cc. As a top candidate of the CS-SMC conductor, the company has proposed and developed the bronze-processed Nb_3Sn conductor. The full-size CS-SMC conductor, having the cable-in-conduit structure, needs a large amount of strand and long lengths. A trial fabrication of the full-size conductor, in which a 200 kg-class billet was used and the strand was plated chromium of 2 gm thickness, has been successfully done. Figure 3, shows the Jc measurements of the strand. Jc at 12T were 650 A/mm^2 and 620 A/mm^2 in the compressive strain condition for strand with chromium plating and without chromium plating, respectively. This value suggests high performance for the above-mentioned development target. Current carrying tests of the full-size conductor have already been performed at JAERI and FENIX of LLNL and satisfactory results of twice as high as the operation current 40 kA have been verified.

In recent years, Furukawa has been developing superconducting cables and conductors for the superconducting supercollider (SSC), the large hadron collider (LHC), the superconducting generator (super-GM), the superconducting magnetic energy storage (SMES), etc.

Advanced Superconductors

For the Bi-based oxide superconductors, the fabrication processing has been advanced step by step, and the weak link problem has practically been controlled. This is available for practical applications in the temperature range from 4.2 K to 100 K, depending on the magnetic field and current density requirements of the practical use. Furukawa has mainly developed the Bi-based superconductors, both of the bulks and the wires since 1988.

The company has two development programs for bulk applications: the superconducting magnetic shield and the superconducting current lead. The superconducting magnetic shielding system provides a very low magnetic field environment which is on the order of terrentrial magnetism (10^{-4}T) or biomagnetism (10^{-10}-10^{-12}T). Through cooperation with Nippon Gaishi (Insulator) Co., Ltd., we have already fabricated and demonstrated a cylindrical magnetic shielding vessel using the Bi-based oxide superconductor for biomagnetic fields that is the size of a human body, and its marketing has been initiated.

The company has also developed current leads incorporating the Bi-based oxide superconductor. In cooperation with Fuji Electric Corp. the 1 kA model leads having Bi-based oxide superconducting bulk bars without metallic sheath materials have been fabricated and tested successfully. An operation of up to 1 kA showed that the helium flow rate needed to maintain a steady state was about ¼ of ordinary copper leads. Superconducting current leads are now under development, extending to the higher current capacity such as 10 ka-class current leads and AC superconducting applications.

Figure 4. Photograph of the 500-A Class Flexible Cable Using the Multifilamentary Silver Sheathed Oxide Superconducting Tapes

For the advanced applications using the oxide superconducting wires, Furukawa has another two development programs for the superconducting power cable and the superconducting magnet. Our feasibility study in collaboration with the Tokyo Electric Power Co. revealed that the AC loss due to the penetration of the magnetic field, even in few hundred gauss, is a very important problem for the AC power cable, where a preliminary stage of the practical application will be for the underground 66 kV-class power cable in metropolitan areas. We have developed and tested various types of model cable. As the most feasible model cable for the practical line, flexible type power cables shown in Figure 4 using the multifilamentary silver sheathed oxide superconducting tapes are out choice and are being developed now.

Fabrication of wires having long length and large current carrying capacity is one of the key technologies for high field applications. Recently Furukawa has fabricated multifilamentary Bi-based oxide superconducting tapes having the excellent critical current density of $6\text{-}8 \times 10^3 A/cm^2$ for more than 100 m length wires and $1.07 \times 10^4 A/cm^2$ for a short length wire at 77.3 K, respectively. These results will be available for the power cable and the high field magnet performed by using the react and wind process.

R&D of Superconductive Technology at Fujikura Ltd.

43070091F Tokyo JAPAN 21ST in English Jun 94 pp 68-69

[Article by Osamu Kohno, manager, Superconductivity Research Department, Materials Research Laboratory, Fujikura Ltd.]

[Text] Already a quarter century has elapsed since Fujikura Ltd. started the development of superconductive technology. The research was concentrated during this period on metallic superconductive wires and magnets as well as oxide superconductive materials.

(1) Metallic Superconductive Wires

The research on metallic superconductive wires has been conducted since the 1970s. In particular, Fujikura perfected its unique internally tin plating method for the manufacture of high performance superconductive wires in the framework of Nb_3Sn wire technology. The forced cooled superconductive wires and magnets with a capacity of 10 kA/10 T, which our firm delivered to the Electrotechnical Laboratory, are showing excellent superconductive characteristics.

The Engineering Research Association for Superconductive Generation Equipment & Materials, established in 1988, is studying the development and application of Nb_3Sn wires made by the in-situ method for the superconductive generator. We have recently been conducting development of alternative superconductive wires using this in-situ Nb_3Sn with a capacity of about 1 kA/+/-0.5T and the high magnetic field Nb_3Sn wire reinforced with in-situ Cu-Nb filaments (Figure 1).

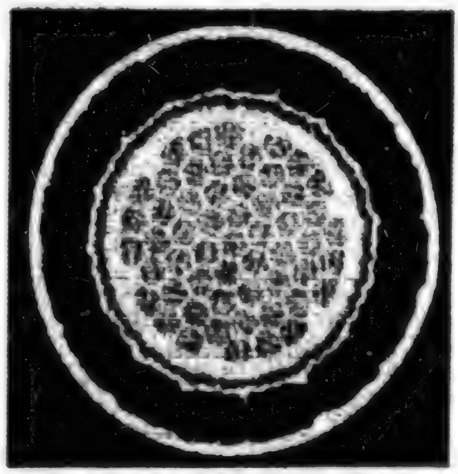


Figure 1. Cross Section of Nb_3Sn Wire Reinforced With In-situ Cu-Nb Wires

(2) Oxide Superconductive Wires

Our firm has taken part in the research on oxide superconductive materials since their discovery, setting the development of the wire forming of various materials as the main research theme. This approach is based on the judgment that long high-performance wires are indispensable for the perfection of the superconductive magnet for the generation of intense magnetic field using liquid nitrogen.

The Y-system is regarded as the most suitable oxide superconductive material for wire forming, taking into

account the liquid nitrogen temperature and a magnetic field of several tesla. Crystal alignment is essential for raising the superconductive characteristics and especially the critical current density (Jc) of a superconductive material in crystal form. The deposition by gas phase process is suitable for crystal alignment of Y-system superconductive materials, unlike Bi-system materials. Hence, Fujikura is manufacturing wires and tapes through thin film deposition on metal tapes by means of the chemical vapor deposition (CVD) method and the laser ablation method.

Figures 2 and 3 are examples of the application of the CVD method. In Figure 2, the metal tape runs in a long chamber and the thin film is deposited through blowing when the tape passes at the middle section of the chamber. Figure 3 shows a tape of about 2 meters in length, on which the film is evaporated through this method.

The Y-system tape produced with the laser ablation method has achieved the most outstanding superconductive characteristics with Jc of $5 \times 10^4 A/cm^2$ at 0T and 77 K and $5.5 \times 10^4 A/cm^2$ at 8T and 77 K. The good crystal alignment achieved through this process is shown by the TEM photograph of the Y-system superconductive thin film (Figure 4).

One model has been proposed for electric power cables in the application of oxide superconductive materials. Figure 5 is a photograph of a long 1-meter model of the superconductive power cable. A block consisting of several silver sheathed Bi-system superconductive tapes is inserted in the spiral groove of the central former for conducting the electric current. This model also comprises the outermost vinyl anti-corrosive layer and will probably set the pace for future development.

We plan to continue our R&D centering on the application of both metallic and oxide superconductive materials.

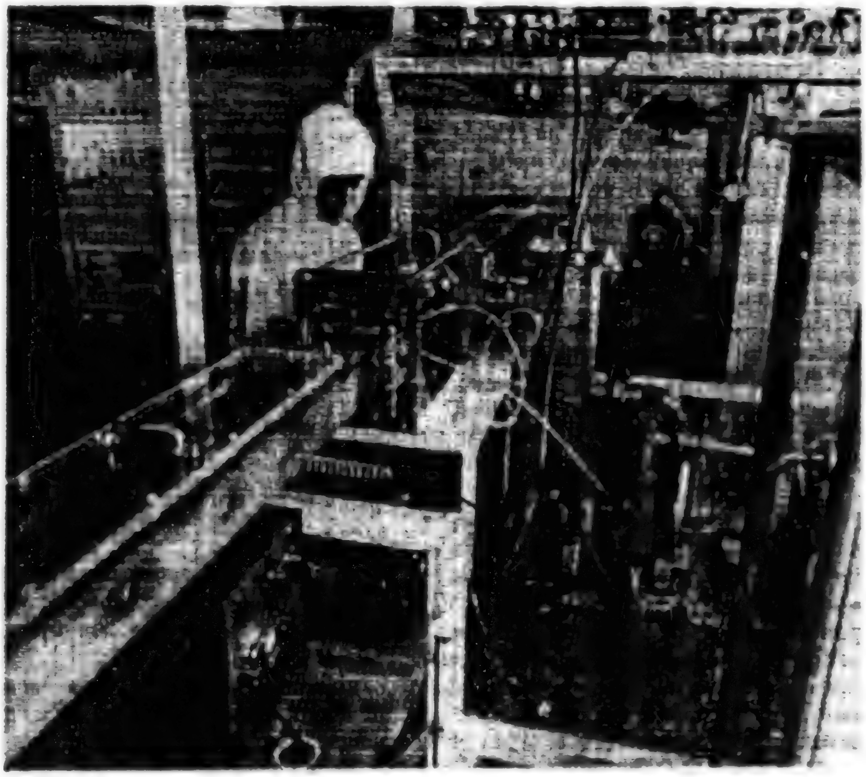


Figure 2. Chemical Vapor Deposition Equipment for Y-System Superconductive Tape

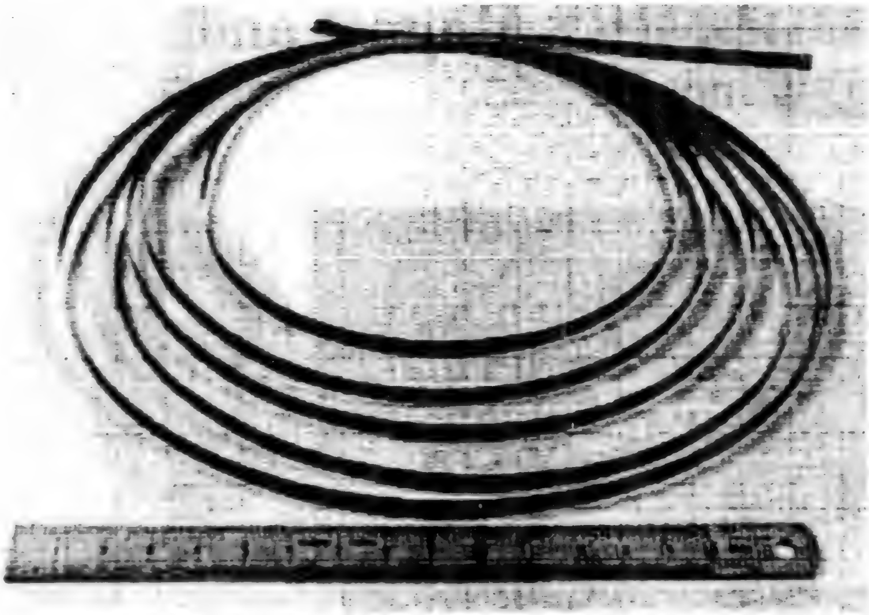


Figure 3. 2-m Long Y-System Superconductive Tape by CVD Process

Figure 4. TEM Photograph of Y-System Superconductive Thin Film by Laser Ablation Process

Figure 5. Electric Power Cable Model With Bi-System Superconductive Tapes

Kobe Steel's 750MHz MRS Magnet and Superconducting Wires

43070091G Tokyo JAPAN 21ST in English Jun 94 p 70

[Article by Masao Shimada, group leader, senior researcher, Superconducting and Cryogenic Technology Center Kobe Steel, Ltd.]

[Text]

Introduction

Kobe Steel, Ltd. (KSL), established in 1905, is a representative multinational conglomerate in Japan, manufacturing iron and steel aluminum and copper and machinery products. In addition, KSL has developed a new business of electronics and robotics, which superconductivity business belongs to.

Activities on superconductivity can be traced back to 1964. KSL has been dealing in superconducting wires and magnets via the Electronics and Information Division since 1985, after a long research period. In 1989, a subsidiary company, Japan Magnet Technology Inc. (JMT), was founded in collaboration with Magnex Scientific Ltd. and Otsuka Electronics Co., Ltd., so as to spread the business worldwide. KSL manufactures and sells superconducting wires and JMT manufactures and sells superconducting magnets mainly for NMR applications. The Superconducting and Cryogenic Technology Center supports both the wire and magnet businesses by means of R&D activities. A recent topic of our activity is described below.

Development of a 750MHz Magnet

Magnet resonance spectroscopy (MRS) is one of the NMR applications and is adopted as an inevitable analysis technology for polymerized and organic compounds. The higher resolution is required, the higher resonance frequency (for hydrogen) is necessary. In other words, the higher magnetic field is a necessity. The highest frequency (or field) of the MRS magnets was 600 MHz (14.1T) till last year. KSL, JMT and Magnex have tried to develop the highest frequency magnet, namely 750MHz (17.6T), according to customers' needs.

The MRS magnet requires quite a high field-uniformity and extremely low field-decay in persistent current operation. In order to achieve the first requirement, the coil configuration of the magnet was studied minutely and was designed to be essentially that of a long solenoid together with a set of outer superconducting compensation coils. The appropriate configuration of solenoids and compensation coils ensured the field uniformity of much less than 0.01 ppm deviation within a sample space.

The second requirement was achieved by the high performance of superconducting wires employed. KSL designed the wires especially for the 750MHz magnet. The high critical current and high quality index "n" at 17.6T at 4.2 K were realized by optimizing the design and production process. These made it possible to fulfill a low field-decay of less than 0.02 ppm/h.

Moreover, adopting the criterion of minimum volume of the windings led to a compact magnet due to optimum grading. This means that our magnet is much lighter and shorter than others. Therefore, the requirements for floor strength and ceiling height where the magnet will be placed are reduced to reasonable levels. The small magnet enables us to design principally the same cryostat, in which the magnet will be supported and cooled down to 4.2 K, as a reliable conventional one.

Performance of the 750MHz Magnet

KSL completed manufacturing and testing the 750MHz MRS magnet last year and shipped it to a customer, the University of Pennsylvania (U. of Penn), United States. At the first run, it showed an excellent balance of uniformity and a low decay in ten days after energizing the magnet on site, as expected from the evaluation before shipping. They succeeded in observing several signal peaks of a certain protein at 17.6T for the first in the world. The photograph [not reproduced] shows the 750MHz MRS system at the U. of Penn. You can see the magnet with the name of JMT on it on the left side and a signal peak on a CRT display. A boil-off rate of liquid helium proved to remain at such a low level that the interval of filling cryogen is sure to be more than two months. The details on this magnet system were announced by both KSL and U. of Penn, at the 35th Experimental NMR Conference held in California in April. JMT is in charge of manufacture and sale on behalf of Kobe Steel group. It expects to sell about five of the 750MHz magnets a year.

Hitachi's Recent Superconducting Technology Activities

43070091H Tokyo JAPAN 21ST in English Jun 94 pp 71-73

[Article by Noboru Suzuki, senior chief engineer, Power Group, and Yutaka Itou, chief engineer, Hitachi Works, Hitachi, Ltd.]

[Text]

1. Introduction

Hitachi has been engaged in on-going research and development of superconducting wires, cables, magnets, generators and refrigerators since 1962. Hitachi has developed and tested products in the above technologies for governmental and private organizations.

In the middle of the 1970s, Hitachi developed a high magnetic field magnet made of a compound superconductor (Nb_3Sn) by the bronze method. As a result, superconductors have been applied to generators, nuclear fusion, accelerators, SMES, MRI, and other versatile products in the 1980s.

Superconducting-applied products have been developed for larger types and higher magnetic fields.

In case of a high field magnetic, for example, Hitachi developed a 20T class large diameter superconducting magnet having an effective bore of 44 mm under the guidance of the National Research Institute of Metals.

This magnet consists of the combinations of four-layer solenoid coils and uses superconductor NbTi in the outermost layer, $(NbTi)_3Sn$ in two intermediate layers, and $(NbTiTa)_3Sn$ in the innermost layer. Hitachi has succeeded in the world's highest superconducting magnetic field of 21T by dipping and refrigerating the outer layer 1, 2 coils into a 4.2 K liquid helium tank, and also, the intermediate and inner layer coils into a 1.8 K saturated superfluidity helium tank.

Now, the recent development status of nuclear fusion, SMES, and superconducting generators will be outlined below.

2. Magnets for Nuclear Fusion

In the magnetic confinement system, various magnetic field configuration have been studied until now.

At present, two systems are mainly being investigated.

One is the tokamak system which positively utilizes the magnetic field generated by exciting a large current in the plasma, while the other is the helical system which contains the plasma in a magnetic field of coils without flowing any current to the plasma. In the tokamak system, International Thermonuclear Experimental Reactor (ITER) is being developed as a next-stage nuclear fusion experimental reactor.

In helical systems, large helical device (LHD) is constructed in National Institute for Fusion Science (NIFS), these systems require a magnet with huge energy storage (GJ).

(1) Tokamak system coils

Hitachi is now developing a forced refrigerating system magnet under the guidance of Japan Atomic Energy Research Institute (JAERI).

This system flows supercritical helium into conductors. Hitachi developed a hollow conductor having a current capacity of 30 kA class for the toroidal magnetic coil. Both high magnetic field $(NbTi)_3Sn$ strand and low magnetic field (NbTi) strand are used as superconductors, and they are encased into a stainless steel case of 3 mm in thickness together with stabilizing copper.

Figure 1 shows a double pancake coil of this conductor with 1 m inner diameter and this coil was tested after assembly into demonstration poloidal coil testing equipment in JAERI.

On the other hand, the center solenoid coil to induce and maintain plasma current must generate a high magnetic field and be used in pulse operation. Accordingly, a cable in conduit type conductor is being developed.

Figure 1. Toroidal Model Pancake Coil (Presented by Japan Atomic Energy Research Institute)

Figure 2 shows its cross section.

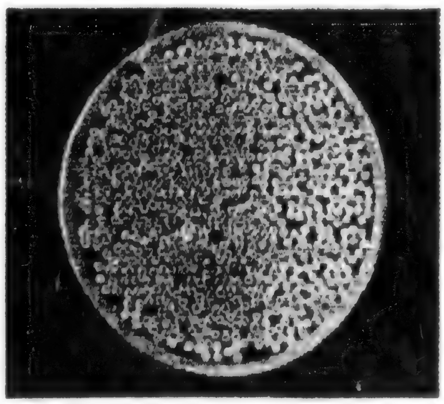


Figure 2. Conductor for Poloidal Field Coils (Conductor: $(NbTi)_3Sn$; Current: 40 kA at 13T; Conduit: Ti,33 mmφ

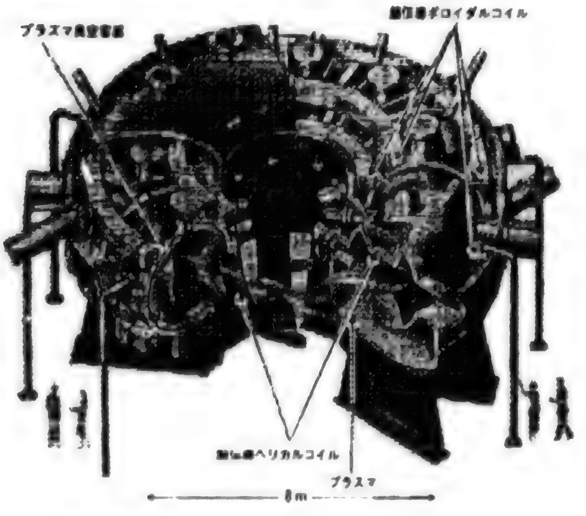
This conductor is prepared by twisting about 675 wires of $(NbTi)_3Sn$ of 0.92 mm in diameter by the bronze method, and encased into a Tl pipe.

Hitachi is now carrying out a 10 kA class excitation characteristic test in a 10T external magnetic field to accumulate various data about superconducting characteristics for designing an actual machine.

(2) Helical system coils

The helical system is characterized by a coil which is wound spirally and continuously around a torus vacuum vessel and requires continuous winding in a three-dimensional space.

Figure 3 shows a bird's eye view of LHD. Hitachi participated in research and development of helical coils from the beginning of the LHD program under the guidance of NIFS. A superconducting helical coil contracted to about 1/5 in principal radius (TOKI-HB) was developed as a prototype for the purpose of confirming the possibility of continuous helical windings with superconducting conductors.



Major radius --- 4m
Plasma radius --- 0.5 ~ 0.6m
Helical field --- 3T

Figure 3. Bird's-eye View of Large Helical Device (LHD) (Presented by National Institute of Fusion Science)

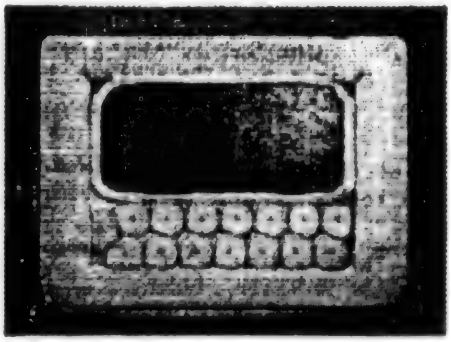
The major radius is 0.8 m, the minor radius is 0.2 m, the magnetomotive force is 1 MA, and the stored energy is 1.9 MJ.

We employed a contracted conductor having a rectangular cross section by assembling an NbTi superconductor and an aluminum-stabilized material, on the assumption of actual equipment. Windings are formed through the winding head where conductors are bent in two directions of their cross sections and twisted by means of the numerical control, and assembled into a bobbin which forms helium vessel.

An excitation test was carried out by combining them with a refrigerator in NIFS. We succeeded in feeding a 9 kA current as a design value, and offered significant data for constructing the LHD.

Hitachi has completed the development of the conductor based on these R&D results and constructed the actual winding machine in the works.

Figure 4 shows the specifications and cross section of the conductor, while Figure 5 shows the helical winding machine being temporarily assembled in the works.



Size --- 12.5 x 18mm
Current ---- 13kA
Conductor --- NbTi
Stabilizer --- Al and Cu

Figure 4. Conductor for Helical Coils of LHD

Figure 5. Winding Machine for Helical Coils of LHD

This winding machine will be relocated to the LHD buildings of the Toki site, and the actual winding of the helical coils will be carried out for about 2 years thereafter.

3. Superconducting Magnetic Energy Storage (SMES)

The SMES seems to be suitable for electric power storage to load level, improve power system stability, and compensate for load fluctuation in electric power systems.

(1) 5MJ SMES developed by Hitachi for in-house experiments in 1984

Hitachi developed a 5MJ SMES to carry out its own experimentation. The aim of this R&D was to research the P-Q decoupling control function of the SMES system in order to improve the power system stability. A 5MJ superconducting magnet, a cryostat made of fiber-reinforced plastics (FRP), a thyristor converter and a microcomputer system were also developed.

(2) 1MJ SMES for Chubu Electric Power Company

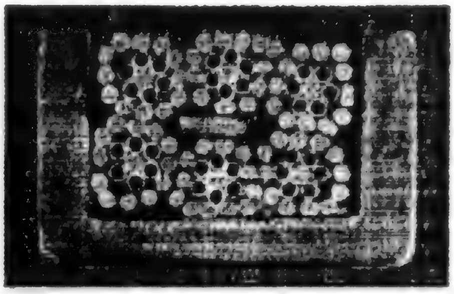
The 1MJ SMES system served the purpose of studying the performance of a power system connecting to an artificial transmission line and performing high strength magnetic field tests. The superconductor was a NbTi wire containing copper and copper-nickel alloy. The cryostat consisted of nonmagnetic material (304 stainless steel). The P-Q decoupling control system using a PWM (pulse width modulation) GTO thyristor converter was provided. It was determined that the 1MJ SMES system could independently control P-Q input/output at high speed.

(3) 1MJ SMES for the Tohoku Electric Power Company

This SMES is given such special features as the enthalpy-wise quench protection, the compacted strands of copper and copper-nickel alloy for the coil conductor, and the optimum configuration of the coil for the least cost. The enthalpy-wise quench protection is considered to be suitable for the future SMES systems and its effectiveness has successfully been examined. The SMES is also provided with a new Q-1 simultaneous control system.

(4) A national development program for the SMES has begun and Hitachi has also been engaging in that development

A 100 kWh/20 MW class (storage energy 480MJ) system is tentatively designed by arranging twelve unit coils in the toroidal form. Hitachi designed the pool cooling system, and developed a 20 kA conductor. Figure 6 shows the cross section and specifications of the conductor. This conductor is constructed by doubly twisting an NbTi strand, burying it into a gate CuNi block together with an aluminum-stabilized material, and then, fixing them by means of soldering.



Size --- 18 x 29mm
Current --- 40kA at 4.3T, 4.3K
Conductor --- NbTi
Stabilizer --- Aℓ

Figure 6. Conductor for 20 MW SMES (Pool cooling)

4. Superconducting Generators (SCG)

Conventional turbine generators are cooled with hydrogen gas or water. The next generation turbine generator, in which the superconducting field winding will be cooled with liquid helium, will have the advantages of improved power system stability, smaller size and higher efficiency compared with conventional generators.

Hitachi has already manufactured and tested a 50-MVA SCG, which, at present, is the largest kind of SCG. Based on the development results of the 50-MVA SCG, Hitachi is now developing a 70 MW class experimental SCG with the goal of finally developing a 200-MW class pilot SCG for the National Project of MITI, being consigned by NEDO, and Super-GM.

(1) The 50-MVA SCG

In the 50-MVA SCG, Hitachi used a cryogenic multicylindrical rotor and an airgap winding stator, two technologies which differ significantly from conventional ones. Accordingly, it was necessary to determine the operational characteristics and reliability of the SCG for practical application. To this end, Hitachi started the development of the 50-MVA SCG in 1974 and manufactured and tested it in 1984.

Synchronous condenser operation was observed as one of the typical operating characteristics of the SCG.

(2) The SCG in the National Project

Since 1988, as a part of the National Project, Hitachi has been developing a highly stable multicylindrical rotor and an airgap winding stator for the 70-MW class experimental SCG aiming at a 200-MW class pilot SCG. For practical use in a power system, it is very important to improve the reliability of the SCG. To this end, Hitachi has already developed the following key technologies:

Al-stabilized superconductor for fully stabilized (quenchless) field winding

Ni-Cu-Al alloy single layer warm damper and Sus-Cu-Sui three layer cold damper by hot isostatic pressing for a multicylindrical rotor.

Double bearings against the thermal contraction of the rotor.

Double transposed stator conductor using rectangular cross-section copper filaments

Comb-shaped GFRP stator coil support for airgap windings.

The reliability of the above key components can be verified by using several partial models, such as the field winding model or stator partial models shown in Figures 7 and 8. Based on proven technologies, Hitachi is now manufacturing a 70-MW class SCG.

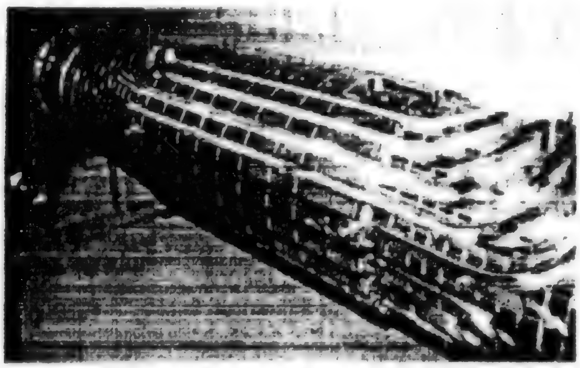


Figure 7. Field Winding Model

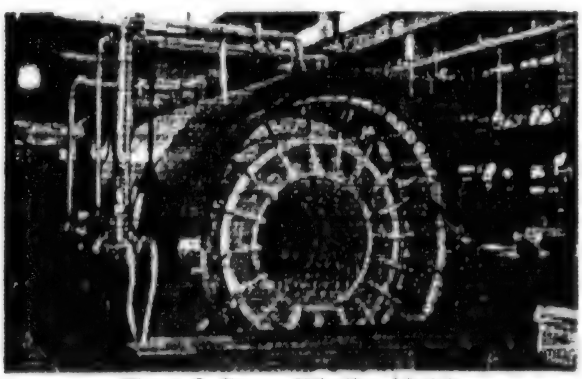


Figure 8. Stator Winding Model

Field test facilities are planned to be constructed by 1996 for the purpose of executing systematic verification tests of 70-MW model machines of various systems.

5. Conclusion

We outlined the research and development of superconducting technology for these past 30 years or so, and summarized recent tendencies regarding magnets for nuclear fusion, electric power storage and generator, etc. The application of superconducting technology in the energy field described in this paper is extensible on a large scale, and high reliability is demanded in addition to its technical completion. It is, therefore, necessary for putting the superconducting technology in practical use to steadily improve the superconducting technology based on the technical breakthrough and demonstration, and also create an environment to accept the application of superconducting technology.

R&D on Superconducting Generators at Toshiba

43070091I Tokyo JAPAN 21ST in English Jun 94 pp 74-75

[Article by Makoto Tari, technology executive, Electric Machinery, Energy System Group, Toshiba Corporation]

[Text]

Introduction

Demand for electric power in Japan is forecasted to grow continuously. In response to this trend, a planned increase of the power supply capacity is underway. Conditions make it inevitable to locate large power resources in remote areas, resulting in longer transmission lines. This has brought less power system stability and an increased cost of transmission line construction. Also, problems are emerging which affect the global environment, such as reducing the consumption of energy and resources. Superconducting technology is expected to make a great contribution toward overcoming these difficulties. Toshiba has joined a major project, Super-GM, and has been actively engaged in research and development on superconducting generators consigned by the New Energy and Industrial Technology Development Organization (NEDO) as part of "R&D on Superconducting Technology for Electric Power Apparatuses" under the New Sunshine Program of the Agency of Industrial Science and Technology, MITI.

Progress

Since the early phase of R&D (research and development) on the s.c. (superconducting) generator, Toshiba has been pursuing its effectiveness and potentiality in an electric power supply system. Among the various advantages of the s.c. generator, one inherent advantage is to improve the stability of the power supply system, because of its high magnetic field. This advantage can be enhanced by an adjustable excitation current, particularly a quick-response excitation control which remarkably improves the power system stability (Figure 1). The advantage reduces construction costs of power transmission lines.

Consequently, under the New Sunshine Program, we have undertaken R&D on a quick-response excitation s.c. generator. Toshiba's program is shown in Figure 2. We are developing technology responsive to the, 200 MW pilot machine through the development of a 70 MW quick-response excitation model machine.

Through the phase of elemental technology development, we are manufacturing a large-sized rotation model which is aimed at evaluating reliability against centrifugal forces. The next phase, already started, is to manufacture the 70 MW model machine to completely verify the quick-response excitation generator.

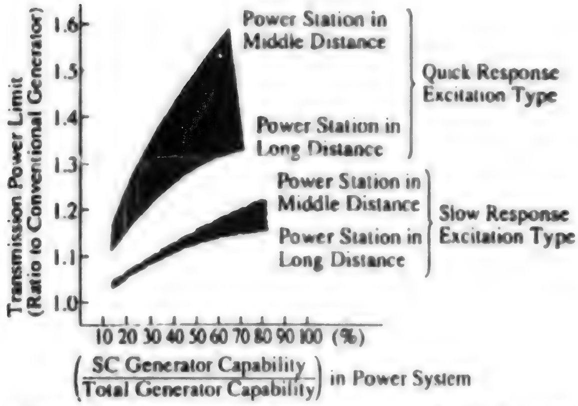


Figure 1. Improvement of Transmission Power Limit (Analysis is by Central Research Institute of Electrical Power Industry)

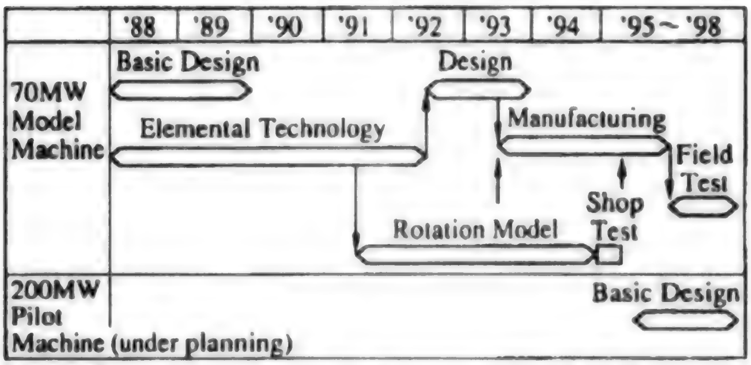


Figure 2. R&D Program of Superconducting Generator With Quick Response Excitation

Research and Development

We have developed key technology for large-sized quick-response excitation s.c. generators. The major research and development items are shown in the following:

Superconducting conductor and field winding

A quick-response excitation generator needs an advanced s.c. conductor with low-AC loss, high-current density and large current (Figure 3). Techniques have been developed for mass-producing the advanced conductor and also for winding it on the winding-support shaft. These techniques have been applied to the rotation model (Figure 4).

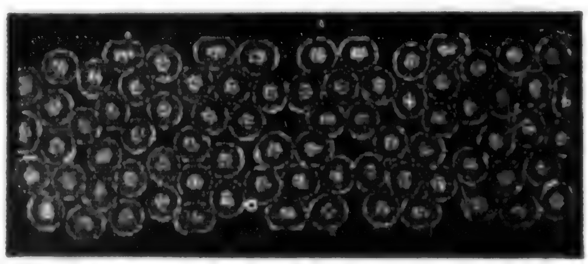


Figure 3. Superconducting Field Conductor With Low AC Loss, High Current Density and Large Current

Winding support shaft

The winding support shaft secures a superconducting conductor against strong centrifugal and electromagnetic forces, while cooling and insulating it. Considering applicability to large-capacity utility machines, we selected a nickel-base superalloy with high mechanical properties and high electric resistance, and have improved it on the weldability and large-ingot producibility (Figure 5). Techniques have also been developed to produce a longer shaft by welding the rotor body longitudinally (Figure 6). Techniques with CAD/CAM systems for precision machining the high strength material into three-dimensional curvature (Figure 7) have also been developed.

Warm damper

At the outermost part of the rotor is a cylindrical electromagnetic damper to protect the superconducting

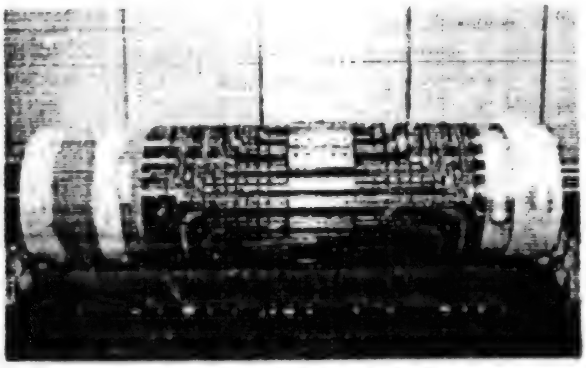


Figure 4. Wound Rotor of Rotation Model

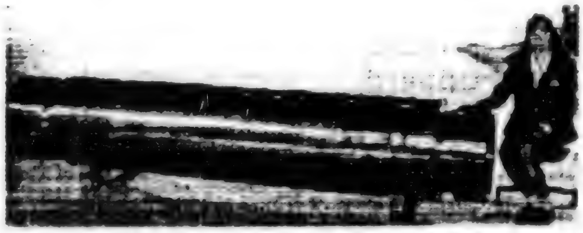


Figure 5. Nickel-Base Superalloy Formed Rotor for 70 MW Generator, the Biggest Forging in the World

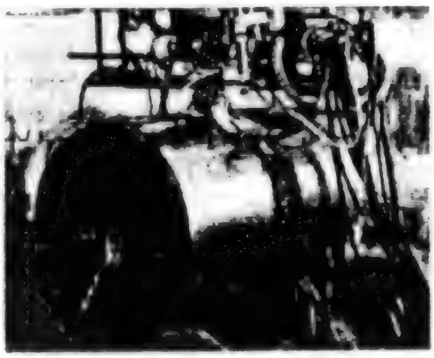


Figure 6. Experimental Welding of Shaft Body

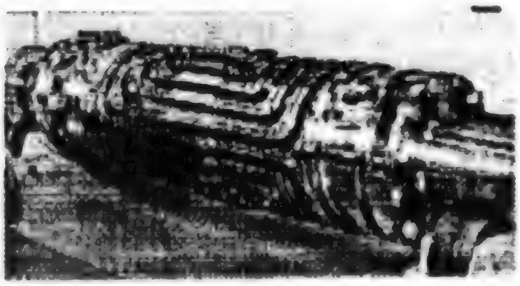


Figure 7. Machined Nickel-Base Superalloy Shaft With Numerically Controlled Machining Technique

winding from fluctuating high-frequency magnetic flux of the 102 Hz level caused by faults or unbalanced load in the power system, while allowing penetration of a quick-response excitation flux of the 1 Hz level. A three-layer damper structure has been selected and developed. With this structure, the copper-alloy cylindrical damper is supported by inner and outer cylinders made of a ferro-base superalloy with high strength. These components arranged in three layers are diffusion-bonded by a hot isostatic pressing method. These techniques were applied to the rotation model (Figure 8).

Figure 8. Warm Damper, Three-Layer Diffusion Bonded—The Biggest in the World

Helium vessel

A helium vessel contains liquid helium in a centrifugal field. Techniques have been developed for manufacturing a large-diameter thin-wall cylinder made of a nickel-base superalloy (Figure 9).

Figure 9. Nickel-Base Superalloy for Helium Vessel in Hollow-Forging Process

Liquid helium in the rotor

In the field of centrifugal force on the rotor, liquid helium is circulated by convection and compressed by itself. Its properties and behavior as coolant are much influenced by centrifugal force and Coriolis force. These on the high-speed rotor are studied and revealed by Toshiba for the first time in the world (Figure 10).

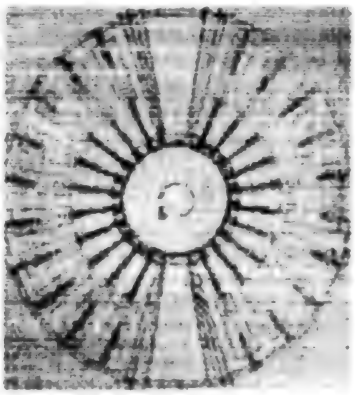


Figure 10. Simulation of Liquid Helium Flow in High-Speed Rotor by Computational Fluid Dynamics

As described above, key technology for practicable superconducting generator has already been developed and is being applied to the rotation model and the 70 MW model machine.

Future Plans

We will manufacture the 70 MW model machine on the basis of production experience and test results of the rotation model. These steps are useful for realization of utility-use s.c. generators.

Toshiba is also proceeding with R&D programs to apply superconductive technology to magnetic energy storage systems, fault current limiters and so on.

At Toshiba, we will contribute to the development of superconductive technology for application in generators and other equipment for electric power systems.

Superconducting Technology Development at Mitsubishi Heavy Industries

43070091J Tokyo JAPAN 21ST in English Jun 94 pp 76-77

[Article by Hiroshi Sakai, chief engineer, and Hiroaki Morita, engineering manager, Information Processing and Electronic Systems Department, both of Mitsubishi Heavy Industries, Ltd., Kobe Shipyard and Machinery Works; and Masaharu Minami, assistant chief research engineer, Mitsubishi Heavy Industries, Ltd., Takasago Research and Development Center]

[Text]

1. Introduction

Mitsubishi Heavy Industries, Ltd. (MHI) is contributing to society and anticipating the demands of the future through its potential for technological development and its capabilities in information gathering. over one hundred years of experience and tradition are behind our outstanding results in the production of a wide variety of products, including ships, power systems, aircraft, chemical plants and industrial machinery.

In view of recent progress of superconducting technology, it is expected that superconductivity will become one of the basic technologies which support industry of the 21st century. Planning for the strategic development of new products utilizing superconducting technology, MHI is now carrying out many research and development activities from the field of basic technology to the field of application technology. We are anticipating that various possibilities will be born from the harmony of extensive technology which we possess as a manufacturer of heavy machinery and superconducting technology. The following areas are mainly considered in this line.

A) Electrical power plants and energy systems

- Superconducting magnetic energy storage systems (SMES)
- Controlled thermonuclear fusion reactors
- MHD generators
- Flywheel energy storage systems

B) Transportation systems for space, oceans, land, and buildings

- Superconducting MHD propulsion ships
- SC linear motor transportation systems
- SC electromagnetic propulsion for rocket launchers
- SC magnetic levitation and magnetic bearings
- SC three-dimensional linear elevator for ultrahigh towerblocks

C) Accelerator

- SC magnet for high energy accelerators
- SC-RF cavity for high energy accelerators
- SC wiggler for free electron lasers

D) High temperature superconductivity

- Wires and bulk
- Magnetic shields
- Motors
- Magnetic bearings

These are only examples, but the one which we want to emphasize is the superconducting MHD propulsion ship. MHI has been researching and developing this new propulsion system since 1986 and built the world's first prototype experimental ship with superconducting MHD propulsion, "YAMATO 1," participating in the Ship and Ocean Foundation project. The success of sea

trials carried out in 1992 was reported all over the world as an epoch-making event. A photograph of "YAMATO 1" at sea is shown in Figure 1 [not reproduced]. Another unique item is the SC linear motor elevator which is being developed with the Power Reactor and Fuel Development Corporation. MHI is not only carrying out basic superconducting technology research, but also the development of its practical applications. Here we will introduce the activities of superconducting technology development for electric power system applications at MHI, especially SMES.

2. SMES

SMES is a system to store electrical power in superconducting magnets as magnetic energy using the characteristics of superconductivity of zero electrical resistivity. Recent development of superconducting magnet technology and power electronics has made it possible to use superconducting magnets for electrical power storage. MHI has been constructing many nuclear and thermal power plants, and in this line MHI is developing SMES as a next generation electric power system in step with MITI and electric power companies.

2.1 Feasibility Study and Design Research

From 1982 to 1985, MHI participated in the feasibility study of large-scale (for load leveling) SMES conducted by NEDO (New Energy and Industrial Technology Development Organization) and ENAA (Engineering Advancement Association of Japan). Following NEDO and ENAA's feasibility study, those activities were taken over by the Research Association of SMES (RASMES). Investigation and evaluation studies of medium size (10 MWH Class) SMES are mainly conducted by RASMES. MHI takes part in the activities and plays an important role in RASMES.

Meanwhile, MHI conducted a design and evaluation study of large-scale 5 GWh SMES, sponsored by the Kansai Electric Power Co., Inc. (KEPCO) from 1985 to 1988. A technological and economical comparison study was carried out for toroidal and solenoidal SMES systems. The toroidal SMES was judged more attractive from the point of leakage magnetic field, manufacturability and maintainability. An illustration of the 5 GWh SMES is shown in Figure 2 [not reproduced].

Since 1992, MHI has been conducting a design and evaluation study of small-scale (100 kWh class) and medium-scale (20 MWh class) toroidal SMES, sponsored by Chubu Electric Power Co., Inc. From the quantitative evaluation, it was clarified that toroidal SMES using racetrack winding coils can store more electric power in a smaller site, minimizing the distance limit of overland transportation. It also clarified that, in medium-size SMES, the idea of multistoried-concentric multilayer toroidal SMES is effective to decrease the site area. Computer modeling of three-storied concentric three-layer toroidal SMES is shown in Figure 3 [not reproduced].

2.2 Development of 2.4MJ SMES for System Stabilization Studies

Since 1988, KEPCO and MHI have been jointly developing 2.4MJ class toroidal SMES for stabilization studies of electrical systems. It is necessary for system stabilization SMES to transfer electrical energy back and forth according to the demands of electrical power systems, so it is essential to develop a superconducting magnet not affected by the change of magnetic field. In 1992, MHI successfully completed a dynamical charge/discharge test of a Nb-Ti pool boiling SMES coil having a rated output of 400 kJ. Figure 4 [not reproduced] shows the outside view of this coil. The test was performed for three hours with a charge/discharge speed of 1 tesla per second (over 1,000 pulse) without any quench, and an electrical power loss of only 0.01% was attained. This is the world's first SMES coil capable of such a high response with only a 0.01% power loss.

To reduce the energy loss caused by eddy current, a copper stabilizer, which is subdivided by a cupronickel layer, surrounds the superconducting material. For the liquid helium vessel to prevent heat generation by eddy current, MHI developed a special GFRP (glass fiber-reinforced plastics) liquid helium vessel. There are many FRP cryostat these days, but this cryostat had the warm bore in the center of the coil and for this reason new development was needed. Namely, in this structure the cryostat should be constructed by the adhesive-bonding method because it is difficult to be constructed in the unit body, and the development of a reliable adhesive-bonding method which ensure the tightness of helium leakage at liquid helium temperature is required. After FEM stress analysis and element tests of adhesive-bonding, we have developed a new type of GFRP liquid helium vessel.

The 2.4MJ toroidal SMES system is composed of six same scale coils, and KEPCO is planning to conduct a part torus test by the combination of several coils and simulation tests on the stability of the electrical power system using this SMES coil system in the near future.

2.3 Development of 100 kWh Toroidal SMES

In 1991, MITI started an R&D program for a 100 kWh class SMES for multipurpose use in electrical power systems, which is reported on in detail elsewhere in this issue. MHI is also participating in the superconducting magnet development program, especially the development of the double conduit type forced cooling Nb_3Sn conductor.

3. Conclusion

Activities of superconducting technology development at MHI, mainly SMES, have been presented. To introduce SMES systems for industrial applications, further development of superconducting technology and improvement of system stability, reliability, and cost competitiveness are needed. MHI has not only key

superconductivity technology and the knowledge of materials, structures, strength, and systems which are necessary to construct commercial power plants, but also the potential to integrate the plants. MHI is committed to carrying out the development of SMES and other superconducting applications.

Cryogenic Turbo Machines and Superconductive Magnets

43070091K Tokyo JAPAN 21ST in English Jun 94 p 78

[Article by Nobuyoshi Saji, manager, Rotating Machinery Group Development Department, General Machinery Division, Ishikawajima-Harima Heavy Industries Co., Ltd.]

[Text] The development of superconductive equipment applied to electric power facilities is intensifying. High reliability during long hours of operation is demanded of the liquid helium refrigerating machine for cooling the equipment. Hence, the use of lubricating oil is undesirable for the helium refrigerating machine. Ishikawajima-Harima Heavy Industries Co., Ltd. (IHI), is working for the development of a completely oil-free helium refrigerating machine by applying the technology of the cryogenic turbo machine.

The oil contained in helium gas in the order of ppm is condensed into liquid and then solidified in a process in which the gas is refrigerated from the ordinary temperature to that of liquid helium (4 K). The solid oil adheres somewhere and causes various problems. The helium gas must be constantly kept in a pure state for the maintenance-free operation of the refrigerating machine for long hours. If lubricating oil is used, its vapor must be removed completely.

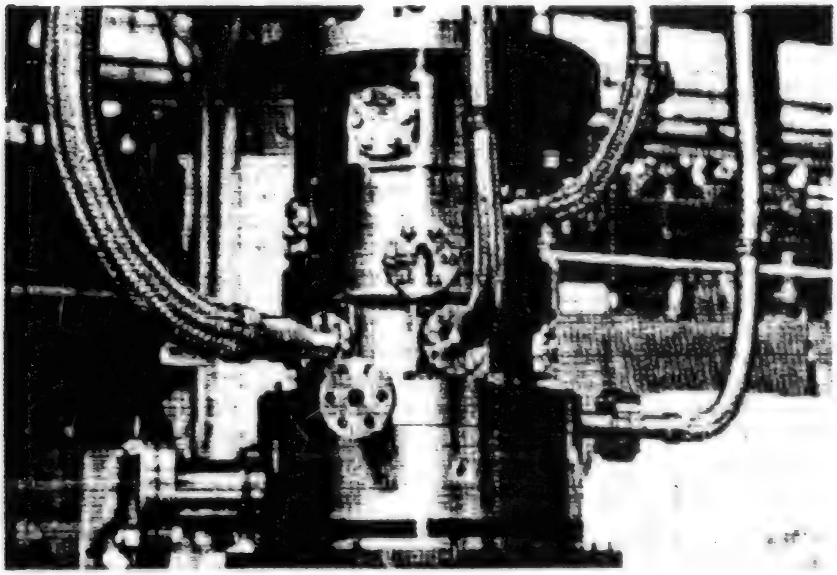
These problems and difficulties can be circumvented completely if the gas bearings for supporting the shafts with gas film or the magnetic bearings for supporting with magnetic force is employed in the rotating machinery using helium as the working gas. The gas bearing has already attained a practical stage in the expansion turbine. A completely oil-free machine is realized if the compressor is freed from lubricating oil.

One of the advantages of a centrifugal compressor is the relative ease of achieving an oil-free structure. Furthermore, maintenance-free operation for long hours is facilitated through the compact size of the high-speed rotating machine and either of the abovementioned two noncontact bearing types which dispense with parts that deteriorate through friction and abrasion. This advantage is an important factor for electric power facilities which must ensure stabilized power supply.

IHI has completed the performance evaluation tests in each stage of the four-stage centrifugal compressor applying magnetic bearings and operating at 80 K for the refrigerating cycle designed for 20,000 hours of MTBM operation. The centrifugal impeller is driven in each stage with the high-speed superconductive machines, each with 25 kW and 100,000 rpm. The total compression ratio is 8. We intend to continue the development of the completely oil-free all-turbo helium refrigerating machine, including a cycle that refrigerates from ordinary temperature.

In addition, the pump for circulating the supercritical helium in the forced cooled coil and a cold compressor that reduces the temperature of liquid helium below 4.2 K occupy a key position in the superconductive technology. The cold compressor is also needed for the production of the extra-fluid helium with a still lower temperature of 1.8 K achieving more stabilized superconductivity.

This research (work) has been carried out as a part of R&D on superconducting technology for electric power apparatuses under the New Sunshine Project of AIST, MITI, being consigned by NEDO.



Development of a Helium Refrigeration System for Superconducting Generators

43070091L Tokyo JAPAN 21ST in English Jun 94 p 79

[Article by Atushi Yasuda, senior engineer, Cryogenic Group, Mayekawa Manufacturing Co., Ltd., Advanced Technology Laboratory]

[Text] The MYCOM R&D group initiated in 1972 the development of a helium screw compressor, foreseeing potential effects when superconducting technology would be brought to various fields. In 1978, MYCOM offered its developed helium screw compressor to the Fermi national laboratory in the United States and gained a worldwide reputation, owing to a profound contribution to the progress of superconducting technology. MYCOM is now engaged in developing an original helium refrigeration system taking into consideration its characteristics as shown in Figure 1, as a part of R&D on superconducting technology for electric power apparatuses under the New Sunshine program of AIST, MITI, consigned by NEDO.

MYCOM's role in the project is to establish a helium refrigeration system which has a liquefying capacity of 100 l/hr, a continuous operation of 10,000 hours and an impurity concentration lower than 0.1 ppm by volume. In order to achieve such a continuous operation, there is a need to enhance the reliability of the most important components, like the screw compressor unit, high and

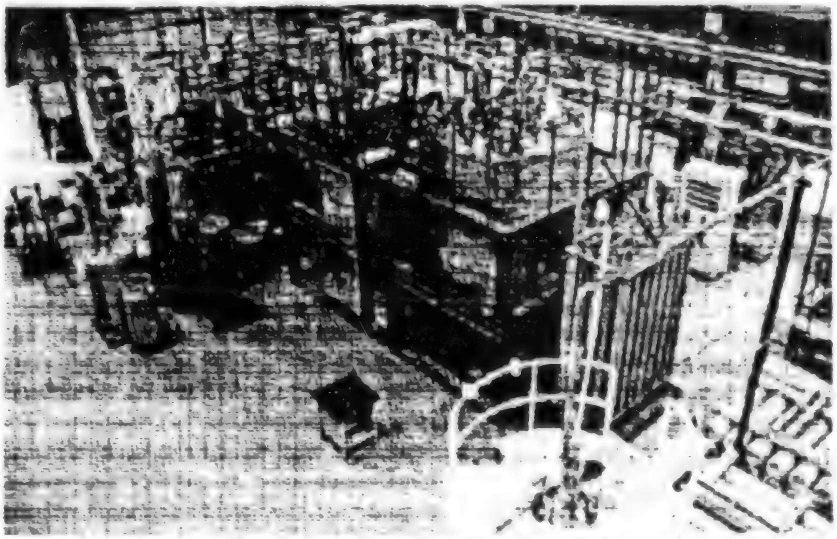


Figure 1. General View of the Developed Helium Refrigeration System

low temperature cold boxes. It was so far verified that the reliability of the screw compressor possesses over a 70,000 MTBF. For the long-term operation of the superconducting generator, a low temperature absorber through which the whole high-pressure gas stream passes is installed in the high temperature cold box, to provide against small quantities of impure gas that might enter the closed helium gas circuit.

Hence the impure gas content in the helium gas is maintained at less than 0.1 ppm by volume. Whereas a control system, a fully automatic operation from start-up to shutdown, is provided to diminish failures due to human errors and it also serves as a controller against emergencies.

The table shows the results of performance testing of main components.

Table. Results of Performance Testing of Main Components

Item		Target	Result
Total isothermal efficiency of screw compressor (%)		54.1	55.1
Impurity removal ability	Dew point (°C)	-90	≦-90
	Impure gas (ppm)	0.1	≦0.1
Adiabatic efficiency of expander (%)		>65	73.0

In the future, a cryogenic system facilitated to practical superconducting power apparatuses must meet the requirements of high reliability and efficiency, and compactness in addition to long-term continuous operation. Namely, an innovative cryogenic system will be demanded.

For that purpose, an oil free screw compressor using no oil lubricant, which is a principal factor of failure caused by an oil contamination in the conventional cryogenic system is needed. The key to success is dependent upon the very development of the oil free screw compressor possessing a considerably high reliability. MYCOM is grappling with this R&D and many studies have been done on rotors free from a thermal strain induced by compression heat, bearing and seal system working for a high speed operation of 20,000 rpm. MYCOM is fully convinced of its ability to demonstrate practical applications.

R&D Project for High-Temperature Superconducting Magnetic Bearing and FRP Flywheel Power Storage System

43070091M Tokyo JAPAN 21ST in English Jun 94 p 80

[Article by Hiromasa Higasa, general manager, Load Leveling Technology Research Division, Shikoku Research Institute Inc.]

[Text] Use of a power storage system to level the electricity supply and consumption patterns provides an effective tool to save energy and cut the power service cost. It is desirable that the flywheel system, which comprises a rotary disk in general, should be designed to achieve higher energy density by turning the disk at high speed and, ideally, to be free of revolution losses, including those at the bearing.

Improvement of Flywheel Power Storage System's Energy Efficiency With High-Temperature Superconducting Magnetic Bearing

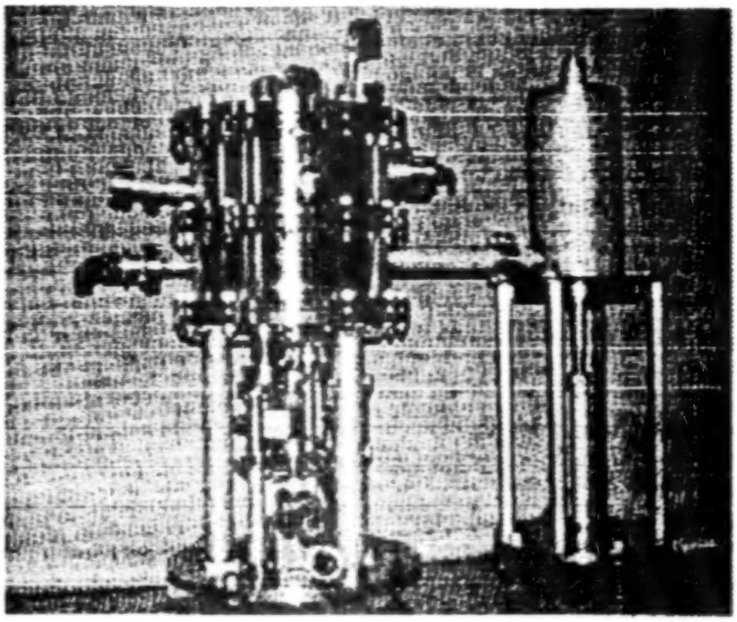
A yttrium-oxide superconductor with strong flux pinning, when combined with a magnet that forms a field gradient, makes a sustained shielding current flow through itself to generate strong repulsion force and attraction force against the magnet so that any change in the magnetic field will be precluded. Theoretically the force working on the superconductor during this process can be written as:

$$F = g\ \mathrm{rad}\ (M\text{-}H)$$

Where M represents the magnet moment and H is the intensity of the field.

A bearing using this superconductive phenomenon has noncontact, noncontrolled support capability to levitate a rotor with a ring magnet attached to its bottom and maintain its attitude above a set of superconductors placed and fixed simply to form a plane surface in the cryostat. At the present stage, 1 kg to 2 kg per square centimeter of the magnet's surface opposed to that of the superconductors may be used as a reference standard for the load capacity of the bearing in designing it. The load capacity is expected to increase in the years ahead mainly through further improvements in crystal orientation and in the field gradient of the magnet.

Revolution losses of the bearing are caused by local disparities in the circumferential magnetic field resulting mostly from joints in the magnet and vibrations of the shaft. Unevenness in the magnetic field results in a hysteresis loss of superconductor magnetization proportional to the first order of revolution rate and in an eddy current loss proportional to the second order of revolution rate. According to measurements recorded at a 100-Wh flywheel power storage system with a superconducting magnetic bearing. The amount of energy that can be stored by such a system per unit volume of superconductors is 3 kW/m^3 at 17,000 rpm. Based on a conceptual design worked out by the authors for an 8-MWh installation, the proposed power storage system can achieve an energy efficiency of 84% in leveling the daily load, taking into account the power conversion loss of the generator motor and auxiliary equipment losses. This means that the superconducting magnetic bearing is very useful for the flywheel power storage system.



[Figure] Appearance of the 100-Wh Class Power Storage System Using High-Tc Superconducting Magnetic Bearing (left, 19-inch diameter, 33 inches high)

Increased Energy Density Through Use of Composite-Material Flywheel With Reinforcing Fibers in Radial Direction

Fiber-reinforced plastic, which is lighter and stronger than metal, has a disadvantage in that its components perpendicular to the orientation of fibers have inadequate stress. To remove this disadvantage, we designed a flywheel using an FRP rotary disk with reinforcing fibers arranged in the radial direction as well as in the circumferential direction. This optimum design enables the flywheel system to achieve a higher energy density, 1.3 times the previous level, when reinforcing fibers in the disk are distributed between the circumferential and radial directions at a ratio of 7 to 3 compared with 10 to 0 in the conventional design. With carbon fibers in a 560 kgf/mm^2 range, it is expected, this fiber orientation will provide a high-energy-density FRP flywheel system that has an energy density of 200 Wh/kg.

Naturally the new technologies described above help reduce the system cost, and further research and development efforts will be made in this field.

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